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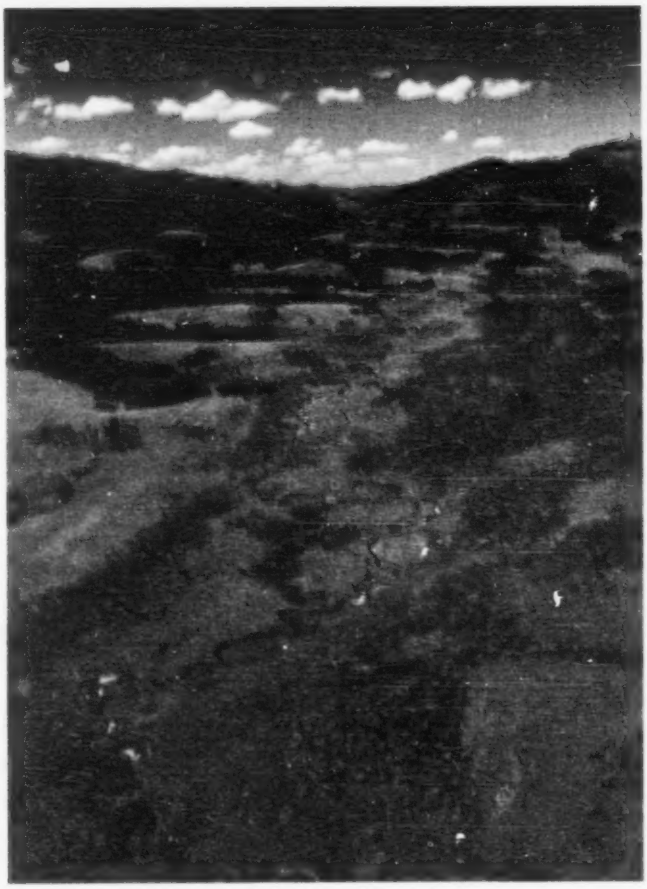
RESOURCE DATA AND SPECIES AT RISK SECTION

The Southern Headwaters At Risk Project: A Multi-Species Conservation Strategy for the Headwaters of the Oldman River

Volume 1 - Introduction and Natural Processes



Alberta Species at Risk Report No. 89

Alberta
SUSTAINABLE RESOURCE DEVELOPMENT

Alberta Conservation Association

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The Southern Headwaters At Risk Project: A Multi-Species Conservation Strategy for the Headwaters of the Oldman River

Volume 1

Introduction and Natural Processes

François Blouin

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EXECUTIVE SUMMARY

The headwaters of the Oldman River Basin flow through a highly variable landscape containing a rich diversity of habitats and species. It is home to a large number of species at risk (At Risk, May be at Risk, and Sensitive designations) and is a critical habitat linkage between the mountain, foothill, and boreal areas to the north, and the Columbian and Yellowstone ecosystems to the west and south. This diverse landscape is also reflected in the diversity of land use in the area. Increasing demand for natural resources, agriculture, development, and recreational activities are increasing pressure on the landscape.

Following their experience for the Milk River Basin (Quinlan *et al.* 2003), a multi-species conservation approach was initiated by the Alberta Fish and Wildlife Division and the Alberta Conservation Association in an attempt to ensure the long-term sustainability of species at risk in the Southern Headwaters At Risk Project (SHARP) area. This volume introduces the SHARP project and presents the most important natural processes and their ecological functions in the area.

Past major geomorphological processes such as mountain orogeny, erosion, sedimentation, and glaciations were responsible for creating much of the landscape found in the SHARP area today. The Grassland natural region to the east has been maintained through time by natural processes such as flooding, drought, wind, fire, and grazing. Flooding and drought conditions affect plant species differently and create communities adapted to their regime and intensity. Fire plays an important role in recycling nutrients but also prevents succession from advancing. Since the European arrival in the area, fire has been relatively controlled and the large herbivores that once roamed the plains and grazed the grasslands are now either extirpated, or have been displaced into the mountains. Domestic cattle are partly carrying out their ecological role, but the structure and composition of many grassland plant and animal communities have been greatly modified.

The cooler and moister Rocky Mountain natural region to the west has allowed forests to become established and to develop as a patchy mosaic of variable size, age, and composition under various flooding, drought, wind, fire, insect and disease outbreaks, and avalanche regimes.

Predator-prey interactions are also a fundamental part of the SHARP landscape. The gray wolf, coyote, cougar, grizzly and black bear, are all major predators on ungulate populations, while wolverine scavenges on carrion in winter or preys on small mammals, birds, and insects in summer.

Natural processes are fundamental in maintaining the ecological integrity and ensuring the long-term survival of species at risk populations in the SHARP landscape.

1.0 INTRODUCTION

The Oldman River flows for 450 km from its Rocky Mountain headwaters into the prairies where it meets with the Bow River to form the South Saskatchewan River. It drains a basin of about 26,357 km^2 (Golder Associates Ltd 2003), and its mean annual flow of 3,191,088 cubic decametres (dam^3) at its mouth (Figliuzzi 2002) provides a fresh water supply to a population and local economy of about 161,500 people (Oldman River Basin Water Quality Initiative 2002). Much of the eastern part of the Oldman River basin has been transformed through intensive cultivation, but relatively undisturbed landscapes shaped by past geomorphological events and on-going natural processes still remain at the headwaters and the upper reaches of the river.

The headwaters of the Oldman River drain the Front Ranges of the southern Canadian Rocky Mountains. The area includes an important part of the Crown of the Continent ecosystem (Gibbard and Sheppard 1992, Flathead Transboundary Network 1999, COCEEC 2002). It provides habitat and essential connectivity for movement and dispersal of several wide-ranging carnivores and ungulates, between protected areas of the Rocky Mountain parks to the north and the Waterton-Glacier International Peace Park to the south, and the western cordillera to the west (Alberta Resource Evaluation and Planning Division 1985, U.S. Fish and Wildlife Service 1987, Boyd *et al.* 1995, Apps 1997, Miistakis Institute for the Rockies 1998).

The diversity of landscape patterns at the gradient between the rolling prairies and the steep Rocky Mountains (Achuff 1994), and the varied climate and moisture regimes (Chetner and the Agroclimatic Atlas Working Group 2003), create a rich mosaic of habitats and diversity of species (Gibbard and Sheppard 1992, Bradshaw *et al.* 1997, Timoney 1998). The area has one of the highest levels of botanical diversity in Alberta. The Castle region alone in the extreme southwest is believed to contain over half of the provincial diversity in plants (Gibbard and Sheppard 1992). Some species are found exclusively in this area of Canada and are at the northern limit of their range (Wallis *et al.* 1986, Gibbard and Sheppard 1992, Smith 1993) and others are provincially or nationally considered at risk of becoming extirpated. A preliminary investigation revealed that eight species (1 plant, 7 animals) occurring in the area were legally designated as "Endangered" or "Threatened" under the provincial *Wildlife Act* or the federal *Species At Risk Act* (F. Blouin; unpublished data). A total of nineteen species were considered "At Risk" under the General Status of Alberta Wild Species 2000 (Alberta Sustainable Resource Development 2001a; Appendix 1). However, the latter examined only orchids and ferns from the plant kingdom. When considering all other vascular plants, liverworts, hornworts, and lichens known to the area, an additional 271 species fell into the "S1" and "S2" categories (provincially at risk; Appendix 2) of the Alberta Natural Heritage Information Centre (ANHIC; J. Rintoul pers. com.). The list gets even longer when the "May Be At Risk" species, those considered sensitive or of special concern, or those for which our knowledge is lacking to make an informed status assessment are considered. Paradoxically, very little research work on the abundance, distribution, habitat use, plant

community types, dispersal, or other ecological associations exists for these species in the area.

The diversity of landscapes also accounts for a diversity of land use in the area. To the east and along the Oldman River and its main tributaries, the rich dark brown chernozemic soil (Achuff 1994, Chetner and the Agroclimatic Atlas Working Group 2003) and the use of irrigation systems have permitted cultivation of various domestic crops species (Oldman River Basin Water Quality Initiative 2002). Intensive livestock operations and urban development are also important in this area. Cattle ranching and some cultivation occur in the eastern part of the foothills fescue prairie, but the western part and the foothills parklands are the core of cattle ranching. Much of the forested mountains to the west are dominated by industrial extraction of oil, gas, and lumber, grazing by domestic livestock, and used for recreational activities such as hunting, fishing, camping, horseback riding and off-road vehicle use, as well as some residential, industrial, and commercial development, all of which are dependant on or highly associated with the development of roads and trails for motorized access (Sawyer *et al.* 1997). Increasing human activity in the SHARP area is putting growing pressure on the natural ecosystems and processes. As a result, natural habitats are being fragmented, degraded, or lost through direct or cumulative effects of development and species are increasingly becoming at risk of extirpation from the area (Sawyer *et al.* 1997).

Objectives:

The task of successfully protecting an increasing number of declining species is thus very challenging, especially when human and financial resources, knowledge, and time for action are limited. A multi-species initiative was thus proposed as an alternative to the resource-demanding species-specific management programs. The MULTISAR: Milk River Basin Project (Quinlan *et al.* 2003) was the first attempt in southern Alberta at developing a multi-species landscape approach to the management and conservation of species at risk. The Southern Headwaters At Risk Project (SHARP) follows the initial footsteps of the Milk River Basin Project. It aims at determining areas of high value for species at risk and developing a cooperative approach at implementing effective conservation, management, and habitat stewardship initiatives in the headwater region of the Oldman River. This project is intended to provide a framework for ensuring the long-term survival of species at risk populations in the area, and preventing others from becoming at risk of extirpation. More specifically, the project objectives were:

- to identify the species at risk in the Southern Headwaters At Risk Project area
- to assess information knowledge and data gaps and design inventory methods for species for which data is lacking,
- to develop a list of focal species for the project through a Delphi process,
- to determine key habitat associations for the focal species and develop Habitat Suitability Index (HSI) models based on available spatial databases for the area,
- to produce a map of relative habitat suitability for each focal species in the SHARP area,

- to identify those areas of the SHARP landscapes that are of high habitat value to individual and multiple species at risk,
- to identify the natural processes of importance in maintaining the ecological integrity of the SHARP area landscapes,
- to evaluate land management systems for their relative value in providing habitat for species at risk,
- to develop a summary of beneficial management practices for the SHARP focal species,
- to provide specific conservation and stewardship recommendations for high priority areas of SHARP,
- to report results of SHARP to communities and conservation groups with an interest in the SHARP area,
- to facilitate partnerships to achieve conservation of species at risk through voluntary stewardship actions.

2.0 STUDY AREA

The Southern Headwaters At Risk Project includes the Wildlife Management Units (WMU) #300-308, #400, #402, and part of WMU #110 west of Highway #2. It thus encompasses the area south of Nanton and Highway #532, west of Highway #2 to the continental divide along the British Columbia border, and north of the United States border and Waterton Lakes National Park (Figure 1).

Figure 1. Southern Headwaters At Risk Project area

The SHARP area covers three major natural regions of Alberta divided on the basis of their broad differences in landscape patterns (Achuff 1994). The grassland to the east makes up almost half (48 %) of the 1,098,292 ha SHARP area. It is represented by a narrow band of Mixedgrass prairie to the east, but largely by Foothills Fescue prairie (Figure 2). To the north and the south, the Foothills Parkland forms a transitional zone between the dryer grassland to the east, and the moister montane forests to the west. This region accounts for only 8 % of the SHARP area and is represented by a gradient of grassland with groves, to forest with grassy parks, to closed deciduous forest, over a short geographic area. The Rocky Mountain natural region to the west makes up the other 44 %

of the SHARP area. It is represented by the Montane, the Subalpine, and the Alpine natural subregions. The montane landscape is characterized by a pattern of open coniferous forests and grasslands. The Subalpine landscape ranges in elevation between 1600 – 2300 m in southern Alberta (Achuff 1994). The lower portion is occupied by closed forests of lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmanni*), and subalpine fir (*Abies lasiocarpa*), while the upper portion is dominated by pure Engelmann spruce stands. The alpine landscape is located above the tree line and is typically represented by a complex, fine scale mosaic of vegetation tightly linked to the local environmental conditions such as moisture, exposure to the sun and the wind, and time of snow melt. (Achuff 1994).

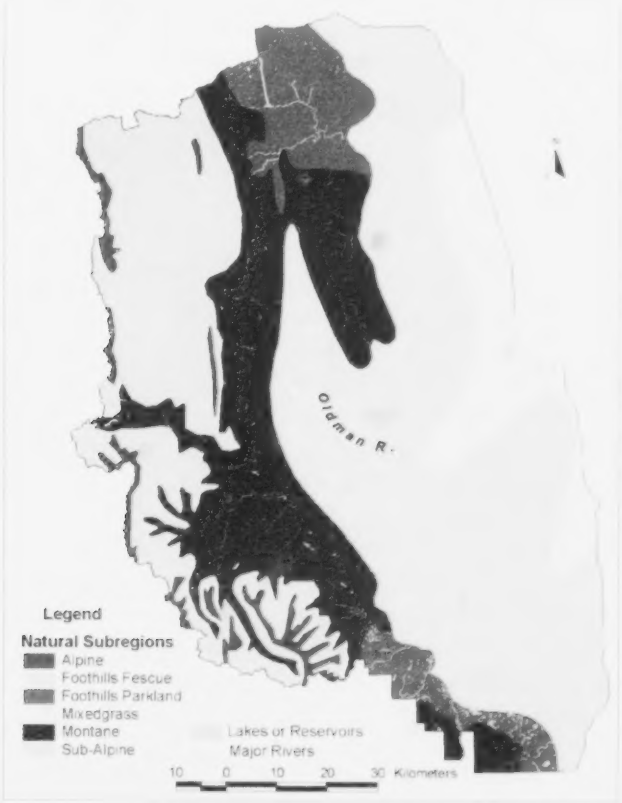

Figure 2. Natural subregions of the SHARP area

3.0 NATURAL PROCESSES IN THE SHARP LANDSCAPE

Introduction

The landscape seen today in the SHARP area is the result of natural processes (abiotic and biotic) that took place in relatively recent geological times as well as during pre-historical and historical times. Some of these processes may still be occurring today. These in turn have affected the abiotic (soil type, chemistry, etc.) and biotic patterns (abundance and distribution of organisms) found on the landscape (Fahrig 2003). Among

the abiotic processes that took place in the SHARP area are major geomorphological events, such as mountain orogeny, erosion, sedimentation, and glaciations that shaped the major landforms and provided them with much of their physical characteristics. They also include the more recent events (cyclic or stochastic) such as floods, erosion, fires, snow avalanches, and droughts, that have taken place afterward and that are still occurring today in a state of dynamic equilibrium. Biotic processes include things such as predator-prey interactions, and insect and disease outbreaks. This volume discusses the most important natural processes taking place in the SHARP area. Although processes are often presented independently of one another, their cumulative effect is responsible for the species composition, distribution, and abundance over the landscape.

3.1. Mountain Orogeny, Erosion, and Sedimentation

The general topography of the SHARP landscapes takes its origin in the Cretaceous period about 70 million years ago. To the west, the land was being raised at a considerable rate. To the east, slow uplifting and gentle wrapping of the continent forced the many seas that had previously covered much of the Great Plains at one time or another to subside. The resulting landscape of the Great Plains is essentially the extensive, nearly flat floor of the former sea (Trimble 1980). With rainfalls in the order of 1000 cm per year (Roed 2001), the rising mountain belt and the volcanoes that appeared 50 million years ago were vigorously being eroded and their sediments transported and deposited at the mountain flanks as gravel, sand, and mud, by the action of rivers and streams (Trimble 1980). The huge coalescing river systems cascading off the highland of British Columbia inundated southern Alberta with sediments that deposited on the plains. Remnants of this event can be found in the sedimentary rock of the Porcupine Hills (Roed 2001).

The Rocky Mountain orogeny, that took place 30 to 50 million years ago, was responsible for the development of the eastern Cordillera. Uplifting accompanied by tilting, easterly push, and erosion created the spectacular topography of the present Alberta Rocky Mountains. The orogenic forces that originated in the west diminished in intensity as they progressively migrated to the east, creating the more rolling younger foothills (Beaty 1975). The east-running rivers and streams in the Rocky Mountains and foothills spread their sediments over the plains (Beaty 1975, Trimble 1980, Levin 1988). Much of these sedimentary rock layers are now found under a thick layer of till and lacustrine deposits resulting from the great ice age that followed (Beaty 1975).

3.2. Glaciation

The pattern of landforms and surficial geology of the SHARP landscape reflects the extensive glacial history that began over one million years ago during the Pleistocene epoch. Climatic variations in the Pleistocene ice age caused the ice sheets that once covered much of Canada to alternatively advance and recede (Levin 1988). Only the last glaciation, the Wisconsin Glaciation, is well known. During this glaciation, the Laurentide ice sheet from the north and the Cordilleran ice sheet from the west converged and covered the entire province, with the exception of parts of the Cypress Hills and

Porcupine Hills (Beaty 1975; Alberta Environmental Protection 1996). In the Rocky Mountains, hanging and U-shaped valleys, and alpine cirques were formed by the carving action of glaciers. These features are still recognizable today (Beaty 1975). The Crowsnest Pass is a good example of a U-shaped valley.

As the last ice sheet retreated about 10,000 years ago, it left behind a thick (up to 100 m) blanket of glacial till east of the mountains (Alberta Environmental Protection 1996) resulting from erosional or depositional processes of glacier retreat. The huge volumes of meltwater generated by the glaciers cut through the till plain and formed long, steep-sided, flat-floored river valleys such as the Oldman River Valley (Alberta Environmental Protection 1996). By the end of this period, the glaciers had sculpted the landforms and altered the drainage of the SHARP area much to what we see it today (Beaty 1975). Undulating high relief, hummocky low relief, and ridged high relief are the predominant landform in the grassland landscape of SHARP, covering respectively 25%, 14%, and 12% of the area (derived from AGRASID; Alberta Soil Information Centre 2001).

3.3. Water Quality, Erosion, Flooding

The rivers of the SHARP area play a crucial role in providing a supply of fresh water, food, and habitat to a wide diversity of plant, invertebrate, and vertebrate species, and a wide array of human uses. Several species are highly sensitive to changes in physical, biological or chemical characteristics of rivers, and as such, are good indicators of water quality. For example, stonefly and mayfly are two benthic invertebrates highly sensitive to organic pollution (Alberta Environmental Protection 1996). The bull trout requires gravelly streams to spawn and high oxygen and cold temperature water for its eggs to develop (Post and Johnston 2002). It is sensitive to decreased water quality resulting from activities that cause siltation, and warming of the water. The harlequin duck is a visual feeder believed dependent on clear streams with healthy macroinvertebrate populations (MacCallum 2001). Water quality is thus essential to maintain the integrity of the aquatic and associated terrestrial processes and to the well-being of the human populations that rely upon it.

Water quality in the Oldman River is affected by seasonal changes in temperature, volume of flow, turbidity and biological activity, and by human sources from industrial, agricultural, municipal, or recreational activities in a way that affects the organisms that live within it or depend on it for their survival (Alberta Environment 1993, Alberta Environmental Protection 1996).

More than 85% of the Oldman River basin's annual discharge takes its source from the foothills and mountains of southwestern Alberta and northern Montana (Mustapha and Figliuzzi 1985). In 1911, realizing the link between forest cover of the mountains and the river waters of the prairies, the federal Government created the Rocky Mountain Forest Reserve throughout the length of the eastern slopes north of Waterton Lakes National Park. Its dual purpose was to protect watersheds and to provide a supply of wood for settlers on the prairies (Murphy and al. 2002). In 1930, jurisdiction of the forest reserve was transferred to the Alberta Government trough the *Alberta Natural Resources Act* and was managed by the Alberta Forest Service. In 1974, following public hearings on land

use and resource development in the eastern slopes, an analysis of public views on the Oldman River Basin revealed that water was the most important resource and the primary guideline in resource management. The Oldman River system was seen as being of critical importance to the region and its headwaters were recommended to receive statutory protection (Sadler 1974).

The SHARP area encompasses twelve major tributaries of the Oldman River that draw their water from the eastern slopes. They include the Livingstone River, Crowsnest River, Pincher Creek, Carbondale River, Castle and West Castle Rivers, Drywood Creek, Dungarvan Creek, Lee Creek, Yarrow Creek, Willow Creek as well as some sections of the Waterton River, and the Belly and North Belly Rivers (derived from 1:20 000 digital base maps - feature: hydrography, Spatial Data Warehouse 1982). In the Rocky Mountains, the major stream valleys lie between 1280 to 1520 metres in elevation and are located among peaks that reach 3200 m in elevation (Mustapha and Figliuzzi 1985). Snowmelt is the primary source of runoff above the treeline where the heaviest snow accumulations are found. Runoff occurs primarily from June through September, with pronounced diurnal fluctuations. Below the treeline, infiltration, evapotranspiration, and runoff characteristics are typical of dense forests. Larger streams cross the foothills from west to east. They leave the mountains at an elevation of about 1280 m and enter the plains region at about 910 m, dropping in elevation by as much as 3.79 m/km of reach (Mustapha and Figliuzzi 1985). In the plains region, the drainage pattern is largely unorganized as a result of a lack of pronounced slopes and the variability in texture.

The eroding action of rivers and streams since the last glaciation has carved deeply into the bedrock and exposed the underlying Cretaceous shales and sandstones in some areas (Achuff 1994). An extensive system of ravines and coulees has also formed along river valleys from the eroding action of melt water and rain. Examples of these are found along Willow Creek, Crowsnest River near Lundbreck, Callum Creek along Hwy #22, Lee Creek, Waterton River upstream from the reservoir, the lower part of Drywood Creek and Yarrow Creek (derived from AGRASID; Alberta Soil Information Centre 2001).

When an increase in streamflow brings the water of a stream to a level greater than what its normal channel can accommodate, causing it to spill on the adjacent land or floodplain, a flood condition is said to occur (Strahler and Strahler 1987, Environment Canada 2002). Streamflow is affected by several factors, which include the amount and type of precipitation, the nature and condition of the drainage basin, and climate. Runoff volume can also be affected by land use changes such as urbanization (Alberta Environmental Protection 1996). In Alberta, episodic flooding can occur after ice jams, rapid snow melt, and/or spring rains, or heavy thunderstorms (Alberta Environmental Protection 1996). More stochastic events such as breaks in natural dams (glacier- or moraine-dams) or man-made dams can potentially create severe floods (Environment Canada 2002). In the Oldman River basin, major floods in the recorded history were caused primarily by heavy rainfall at the time of relatively high mountain snowmelt (Mustapha and Figliuzzi 1985, Alberta Environmental Protection 1996, Rood *et al.* 1998). The storms that generally produce major floods in the foothills are low-pressure systems that originate off the west coast of North America and travel eastward across the

continent. The systems draw warm and moist maritime air from the Gulf of Mexico and mix it with colder polar air at the ground surface. The counter-clockwise circulation directs the moisture-laden air toward the foothills and mountains. As the air rises, it cools, becomes saturated, and heavy rainfall may result in the foothills and along the easterly range of the Rocky Mountains (Mustapha and Figliuzzi 1985).

Flooding and the associated processes of erosion and deposition create a mosaic of habitats in the floodplains, contributing to the species richness. Unique features created by these processes, such as cutbanks, terraces, and canyon walls provide habitat for species like the prairie falcon. Flooding deposits woody debris that improve fish habitat. It scours out pools in the floodplains, creating productive wetlands, and deposits mineral and nutrient-rich sediments and seeds in the floodplains (Gauthier *et al.* 2003). The floodplains ecosystems have adapted to the long-term cycles of high and low water and to the rapid seasonal fluctuations (Environment Canada 2002). Some species have developed adaptations to flood conditions. For example, cottonwood trees (*Populus deltoides*, *P. angustifolia*, and *P. balsamifera*), common in river valleys such as the Oldman, the Belly, and the Waterton Rivers, produce seeds that rarely sprout without flood (Rood and Mahoney 1991, 1995, Rood *et al.* 1998).

High floods have occurred roughly every eleven years in the Oldman River Basin. High floods occurred in 1897, 1902, 1908, 1915, 1927, 1948, 1953, 1964, 1975, and 1995 (Mustapha and Figliuzzi 1985, Rood *et al.* 1998). However, meteorologic and hydrometric networks were quite sparse prior to 1953, making flood analyses difficult (Mustapha and Figliuzzi 1985). The flood of June 1995 was dubbed the flood of the century. Heavy rain in early June coupled with melting snow resulted in the highest flood conditions on record in the Oldman River Basin (Rood *et al.* 1998). In the Castle River drainage (north of Waterton Lakes National Park), 300 mm of rain fell over a 24 hr period on June 5 and 6. Stewards of the Castle-Crown Wilderness Coalition reported 13 areas with major erosion, stream degradation from sediments, and new erosional gullies (Fischbuch and Brodersen 1995). However, there is a high degree of spatial and temporal variability in the contribution of various streams to a flood event in the Oldman River Basin. Some tributaries may be experiencing higher flood peaks than others depending on where the climatic event that lead to the flood is centered (Mustapha and Figliuzzi 1985; Alberta Environmental Protection 1996).

The Oldman River Basin is located in one of the driest area of Alberta. River flow can vary dramatically from year to year depending on the amount of snowfall and rainfall. Flow can vary from near-record highs in one year to near-record lows the next year and remain low for several years, such as in the 1930's and the 1980's (Glenn 2000). High water demand, primarily for irrigation farming, led to the construction of several dams and diversion structures in the Oldman River Basin since the late 1940's (Glenn 2000). There are currently four major dams and reservoirs in the SHARP area, on the Oldman River, Waterton River, Willow and Pine Creeks (Alberta Environment 2003). A certain level of flood control is afforded by these reservoirs (Alberta Environment 1999), but there are concerns that reduced flooding due to these infrastructures will negatively impact riparian diversity and reduce fish habitat connectivity in the Oldman River Basin

(Rood *et al.* 1998, Golder Associates Ltd. 2003). The Oldman River Dam Environmental Advisory Committee (2001) recommended that the Oldman River Dam be operated when conditions permit to provide the flow necessary for cottonwood seedling recruitment and long-term riparian forest maintenance, as well as recharge of floodplain groundwater levels. It also recommended allowing water fluctuations in order to support total ecosystem health and further stressed that current and future water demands must not compromise the Oldman River ecosystem.

It is expected that the risks of extreme flooding in small rivers of the southeastern slopes of the Rocky Mountains will increase with the apparent change in climate that we are experiencing (Ashmore and Church 2001).

3.4. Wind

The high wind regime of the southern prairies exceeds that of most of the world's hot deserts (Muhs and Wolf 1999). The SHARP landscape falls within a region that is affected by a class of fehn winds called "Chinook". Those winds can be very gusty and often reach over 60 km/h. When the water-laden warm Pacific air is carried eastward by westerly winds it encounters the first mountain range where the air rises, expands, cools, and releases its moisture on the west slopes. The dry air that descends on the east side of the mountains heats up by compression and thus becomes warmer and drier. This process repeats twice more before reaching Alberta, raising the temperature by 8 to 10° C above that of the Pacific air. Winter Chinooks can raise the temperature well above 0° C and melt the snow. Southern Alberta, and especially the area of the Crowsnest Pass, gets an average of 30 Chinook days per year (Doerksen 1998). The warming effect of the chinook winds near the mountains produces a west to east trend in winter temperatures (Chetner and the Agroclimatic Atlas Working Group 2003).

Wind has a major impact on the ecosystems of the SHARP area. Chinook winds moderate the effect of cold Arctic air in winter and often melt the snow, providing increased browsing and grazing opportunities for white-tailed and mule deer, elk, moose, mountain goat, bighorn sheep, and other herbivores. One of the direct effects of strong winds in the forested areas include windthrow, which will generate new microhabitats for wildlife, and open areas for early successional plant species to establish. Chinook winds increase evaporation and can increase plant water stress in areas already suffering from low precipitation (Chetner and the Agroclimatic Atlas Working Group 2003) or at times when the ground is still frozen. They play a role in the process known as "red belt". Red belt is a reddening and dessication of conifer needles that occur during unseasonably warm dry winds when the frozen ground prevents compensating moisture from rising to the needles. This effect is more common on the steep mountain slopes, where there is less mixing with cold air and insolation is more direct (Huculak and Little 1999). This was observed in the Kananaskis valley in 1985 (Huculak and Little 1999) and near Hinton in 1997 (Anonymous 1997). Winterkill of trees is a similar phenomenon that occurs on flat terrain.

It is difficult to determine how the effect of wind on the SHARP ecosystems has changed over time. Winds are driven by climate and climates have been changing over the prairie

since the last glaciation (Lemmen *et al.* 1997). It is expected that the current climate change will have an impact on wind patterns and may increase the frequency of severe weather events (Smit *et al.* 2000, Anonymous 2002).

3.5. Natural Processes of the Grassland Natural Subregions

Grasslands can be defined as terrestrial ecosystems dominated by herbaceous and shrub vegetation, maintained by natural processes such as fire, drought, frost, or grazing (World Resources Institute 2000). Other biotic and abiotic factors occurring either singly or collectively have also contributed to the origin and maintenance of grasslands. These include heavy rains, snow, hail, and high winds, climatic fluctuations, as well as factors such as the presence of certain mycorrhizal and other fungi, decomposition rates, allelopathic effects of plants, diseases, insect activities and infestations, predator-prey relationships, animal migrations, animal population increases, browsing, girdling, trampling, wallowing, digging, and burrowing activities (Vogl 1974). These processes are dynamic and vary greatly in intensity, extent, time, and geographic location (Alberta Prairie Conservation Forum 2003)

3.5.1. Fire

Fire probably became an important process in grasslands communities after large tracts of grassland favourable to widespread repeated fires were established (Vogl 1974). Climatic extremes created by variations in rainfall and/or temperatures and edaphic conditions likely helped promote herbaceous species and developing grasslands at the expense of woody vegetation that survive best under more stable conditions (Vogl 1974, Wright and Bailey 1982).

Wildlife response to grassland fire varies depending on the species need for cover, forage, or prey availability. Post burn plants are preferred by herbivores that seek more palatable and apparently more nutritious forage (Vogl 1974). Bison and bighorn sheep habitats, summer deer habitat, and wintering elk habitat are thought to be improved by an increase in the grass component and an increase in nutritional quality of grasslands following fire (Higgins *et al.* 1989). Small mammals may directly be burned by fire or may be exposed to avian or mammalian predation due to a lack of cover immediately following fire. A decrease in vegetative cover also results in a decrease in microhabitats, which can affect small mammal population densities, especially rodents. On the other hand, seeds and invertebrates become available to small mammal granivores and omnivores from removal of the litter layer, while herbivores are limited, especially on complete burns (Higgins *et al.* 1989).

Several factors can affect the response of grassland plants to fire. These include the type of grassland community, fire history, fuel and soil conditions, wind speed and direction, air temperature, and time of the day of fire (Higgins *et al.* 1989). Timing of fire with respect to plant phenology and the frequency of fire will also influence which species it will suppress or promote (Vogl 1974, Higgins *et al.* 1989). However, drought conditions at the time of a fire are the most limiting environmental factors to grass production

(Wright and Bailey 1982, Higgins *et al.* 1989). Because of the complexity and interaction of factors and the lack of data concerning burns on the same community under similar circumstances, results of fire effects are sometimes confusing and misleading (Higgins *et al.* 1989).

Much of the information on the effect of fire on prairie grassland vegetation derives from studies of prescribed burns at different times of the year and under various conditions. Burning has generally been found to increase the production of most grassland vegetation communities. Recurring fires typically promote grasses at the expense of woody species. However, in some occasions, it has no effect on or will even kill individual plant species (Vogl 1974). In the Northern Great Plains, fire has been found to remove excessive amounts of litter that accumulates and usually causes degeneration of grasses and reduction in yields, and to control woody vegetation with moderate damage to the grasses (Higgins *et al.* 1989, Wright and Bailey 1982). It releases the nutrients contained in the litter and makes them available to the post-fire vegetation (Vogl 1974). Fire allows the soil to warm up earlier in the spring and warm season grasses to grow at an optimum rate under adequate moisture conditions (Higgins *et al.* 1989). Depending on the timing of fire, it can decrease species competition of native species with invaders such as bluegrasses (*Poa* spp.) and thus produce higher yields (Higgins *et al.* 1989). It can also favour invaders, opportunistic pioneers, annuals, short-lived perennials, and vegetatively reproducing perennials by opening the soil and providing full sunlight (Vogl 1974). Seed germination of native annuals is also promoted after a fire due to solar radiation (Higgins *et al.* 1989). However, fire can be detrimental to most actively growing annuals (Vogl 1974).

In the more mesic mixedgrass prairie of the Mixedgrass natural subregion (Figure 2), studies of prescribed spring burns showed a variable increase in production of many warm-season grasses according to the amount of moisture and litter accumulation prior to and after burning (Higgins *et al.* 1989). The green needlegrass (*Stipa viridula*) and the exotic bluegrasses are negatively affected by early spring burns, while most other grasses appear to be tolerant of fire when soil moisture is adequate (Wright and Bailey 1982). A hot late May fire in western North Dakota resulted in a decreased frequency of certain grass species and an increase in others, but likely decreased the overall aboveground biomass for several years. A fall burn resulted in only few changes in species composition after 4 years (Dix 1960).

The grassland of the Foothills Parkland subregion is the same as in the Foothill Fescue subregion of SHARP (Figure 2; Achuff 1994). The effect of fire on that fescue prairie vegetation also depends on several variables. In southwestern Alberta, wildfires have been found to reduce aboveground biomass, plant vigour, basal area, leaf length, and number of flowering culms in a rough fescue-Parry oatgrass (*Fescuta-Danthonia*) community (Wright and Bailey 1982), but no information was provided about timing and conditions of the fires. Timing of fire with respect to plant phenology appears particularly important in the way rough fescue (*Festuca campestris*) responds to fire. Spring burning prior to plant growth did not affect the aboveground biomass in the first year, and increased it significantly in the second year (Wright and Bailey 1982). However, spring

burning after growth initiation was more detrimental to the plant than prior to growth. A July wildfire near Miss ula, Montana reduced bluebunch wheatgrass (*Agropyron spicatum*) and Idaho fescue (*F. idahoensis*) cover and frequency, but maintained those of rough fescue. The characteristics of the foothill rough fescue and the bluebunch wheatgrass (*Agropyron spicatum*) make them less susceptible to continuous burning within the plant after the passage of a flame than Idaho fescue. Foothill rough fescue and the bluebunch wheatgrass form larger bunches, have coarser stems, and less fine fuel close to the meristem region (Wright and Bailey 1982). Nevertheless, under very dry conditions, a backfire, a slow-moving headfire, or continued burning of clumps after the fire front passes, can cause severe damage and high mortality to these big bunchgrasses (Wright and Bailey 1982).

In a rough fescue-western porcupine (*Festuca-Stipa*) plant community in the central Alberta aspen parkland, fire generally increased cover and frequency of most forbs (Bailey and Anderson 1978). Foothills grasslands actually have greater forb diversity and cover than central Alberta fescue grasslands (Achuff 1994). Annual spring fires also increased the frequency and stem density of woody vegetation such as silverberry (*Elaeagnus commutata*), saskatoon (*Amelanchier alnifolia*), prairie rose (*Rosa* spp.), and aspen (*Populus tremuloides*) suckers, but reduced the frequency and stem density of snowberry (*Symphoricarpos occidentalis*), prickly rose (*Rosa acicularis*) and wild raspberry (*Rubus strigosus*) (Anderson and Bailey 1980). The rough fescue-western porcupine plant community is well adapted to fire.

There are limited accounts of historical fires in the Great Plains, and no reliable fire frequency records because of the lack of trees to carry fire scars from which to derive fire frequency estimates (Wright and Bailey 1982, Higgins 1986). According to Wright and Bailey (1982), fire frequency on the Great Plains was likely high because early explorers and settlers were concerned about the danger of prairie fire. They estimated a "natural" fire frequency of one every 5-10 years in a level to rolling topography. Higgins (1984) determined that the frequency of lightning-set fires alone on a grazed mixed-grass prairie of south-central North Dakota was once every 12 years, while that of a mixed-grass prairie in the badlands of western North Dakota was once a year. These numbers are likely conservative, as they do not take into account other sources of prairie fires. Higgins (1984) also observed a higher frequency in western parts of North Dakota and South Dakota than in the eastern parts of the Dakotas that he attributed to more xeric conditions in the west. Peter Fidler (1793) in his 1792-1793 diary talks of the fescue grassland of southwestern Alberta as being "constantly on fire" in one place or another, with lightning frequently kindling the grass in the spring and fall, and the Native people in winter. Other historical records tend to indicate that grass fires were persistent on the Northern Great Plains throughout the period of 1750-1900 (Nelson and England 1971).

Although grassland fires around the world have been caused by lightning as well as by spontaneous combustion, sparks from falling rocks, and volcanic eruptions, it is agreed by most ecologists that a common and widespread cause of grassland fires was man (Vogl 1974). Native Americans selectively burned some areas of the prairie grasslands and aspen parklands at certain times in order to ensure conditions adequate to

maintaining their ways of life (Murphy 1985). They used fire to communicate, to improve forage for horses and game species, to improve hunting grounds and facilitate stalking, driving, or surrounding of game species (especially bison), to enhance production of certain food and medicine plants, to clear campsite areas in order to reduce fire hazard, clean up wastes, for warfare purposes, to control insect populations, and for ceremonial and superstitious reasons (Nelson and England 1971, Arthur 1975, Barrett and Arno 1982). Often they accidentally lost control of the fires they started (Nelson and England 1971, Murphy 1985). The effect of deliberately set fires was likely extensive in dry periods owing to the continuity of fuel in the grasslands (Wright and Bailey 1982, Murphy 1985). However, fires were generally set on the plains in autumn and early spring, with fires set during one season, bringing benefits during a later one (Arthur 1975, Murphy 1985).

The arrival of the first Europeans in southern Alberta starting in the late 1850s and early 1860s and the first settlements in the 1880s resulted in an increased frequency of man-related fires (Nelson and England 1971). Fires were either deliberately set on the prairies to clear the land for cultivation, or by simple negligence. Negligence during the construction of the railway and sparks generated by engines during their operation are also thought to have caused numerous prairie fires (Murphy 1985). The extermination of the great bison herds around that time may have also led to extensive areas of longer grass and thick litter accumulations, creating conditions more favourable to fires (Nelson and England 1971). Historical records on the Northern Great Plains point to the fact that natural and cultural causes of fire have been inseparable since at least 1750. The cultural use of fire by native people observed by early explorers, makes it certain that this was also true well before the first Europeans arrived on the prairies (Nelson and England 1971).

Although cultural obstacles such as rights-of-way and cultivated land, and practices such as heavy grazing, and new fire suppression techniques have modified the extent and frequency of natural fires in the Northern Great Plains (Higgins 1984), extensive natural fires still occur on the grasslands (Rowe 1969). From 1949-1964, an observer noted a dozen grassland fires caused by lightning during the 15 years he worked at a range research station in southern Alberta (Nelson and England 1971).

Fire suppression in the grasslands because of strict fire control enforcement since the early 1900's (Murphy 1985) has transformed the structure and composition of many grassland plant communities (Daubenmire 1968, Bailey and Wroe 1974, Wright and Bailey 1982). While grazing is known to approximate the effects of fire (Bradley and Wallis 1996), litter buildup in absence of fire and light or no grazing usually causes grass stands to degenerate and aboveground biomass to diminish (Higgins *et al.* 1989). In Alberta, fire suppression has allowed woody vegetation such as willow, white spruce (*Picea glauca*), and Douglas-fir (*Pseudotsuga menziesii*), to encroach on the fescue grasslands (Moss and Campbell 1947, Johnston and Smoliak 1968, Bailey and Wroe 1974, Wright and Bailey 1982). Both fire and grazing can set succession back and prevent woody vegetation encroaching into the grasslands (Bradley and Wallis 1996).

3.5.2. Grazing

In pre-Columbian times, bison were one of the most important grazers on the grasslands where they occurred and likely played a significant role in their ecological processes (Bradley and Wallis 1996, White *et al.* 2001). Although their exact numbers were never known, they were estimated to be between 40 and 60 million across North America (Seton 1929), and several million were likely present in western Canada at any given year (England and DeVos 1969). Archeological evidence suggests that bison populations also occurred in low densities in high elevation areas and mountain valleys in the parklands and Rocky Mountains (Malainey and Sherriff 1996, Kay *et al.* 1999), but likely spent part of their life in the nearby prairie where warm season grasses are present (Langemann 2000). They may have been found most often in valley bottoms during the fall and winter (Moodie and Ray 1976), where they favoured forage species adapted to relatively low intensity, dormant season grazing such as rough fescue (Johnston 1961, Johnston *et al.* 1971), as suggested by White *et al.* (2001). Other large herbivores such as deer, elk, bighorn sheep, and moose were also present in the grassland, aspen parkland, or Rocky Mountain ecosystems of the SHARP landscape where bison were found, contributing to the impact of grazing, browsing and trampling on these ecosystems (England and DeVos 1969, Bradley and Wallis 1996). Herds of these ungulates roamed between vegetation patches in various stages of post-grazing and post-fire recovery in a shifting vegetation mosaic. Climate further accentuated this grazing pattern, and may have been an important process in promoting vegetation-herbivore stability in the Great Plains grasslands (Ostlie *et al.* 1997).

The response of grassland animals to grazing is highly variable and depends on the pattern of disturbance patches present in grasslands under which the species evolved. For example, various grassland bird species are either grazing-tolerant, -dependant, or intolerant. The degree of grazing determines (at least in part) the avifaunal population composition supported by the area (Ostlie et a. 1997).

The impact that bison had on grasslands varied with population density (Larson 1940), and foraging movement patterns resulting from habitat conditions and predator avoidance (Bamforth 1987, Epp 1988, Carbyn *et al.* 1993. Their gregarious nature in herds of up to 10,000 animals (Roe 1970) and historical accounts suggest that locally they may have had a significant impact and likely overgrazed some areas on the Canadian grasslands (England and DeVos 1969). However, their migratory nature also ensured that it could be several years before they returned to the same specific area, allowing the grass to recover.

Grazing and defoliation studies on rough fescue grasslands showed marked effects under various regimes. A long-term (10 years) season-long grazing study revealed that percent basal area of rough fescue decreased from 7.2 % after light grazing to 0% after heavy grazing (Johnston 1961). Fescue grassland pastures with percent basal area dominated by Parry's oatgrass (*Danthonia parryii*) switched dominance to foothill rough fescue after eighteen years when ungrazed or lightly grazed (Johnston *et al.* 1971). Conversely, very heavy grazing resulted in a lower percent basal area for rough fescue and a higher one for Idaho fescue, other grasses, forbs, and for shrubs, compared to ungrazed or lightly grazed pastures. Change in percent basal area of vegetation was accompanied by a change in

yield as grazing increased in intensity. Weekly defoliation of rough fescue through clipping to 5 cm stubbles from mid-May to late June resulted in 71% mortality and severely reduced vigour in surviving plants (McLean and Wikeem 1985). This proportion increased to 92% when an early September clipping was added to remove regrowth. Reduced injury occurred when clipping was limited to early spring or when 10-15 cm herbage was retained. Both season-long defoliation to 20 cm or clipping only in the fall caused no apparent damage. Rough fescue is extremely susceptible to grazing during the growing season (Walter *et al.* 1996). Increased grazing intensity, grazing season, or height of defoliation negatively impacted rough fescue and modified productivity and species dominance in rough fescue grasslands.

Grazing intensity also affected the height of standing and fallen litter, the amount of litter, the live vegetative cover, and the percent bare ground in a continuously grazed foothills fescue (Naeth *et al.* 1991). Live vegetative cover was highest under light and moderate grazing, intermediate under heavy and very heavy grazing, and lowest in the non-grazed control. The mass of standing litter and the height of standing and fallen litter decreased with grazing intensity. Bare ground increased under moderate, heavy, and very heavy grazing regime. Thus heavy to very heavy grazing negatively affected litter accumulation, vegetative cover and the amount of bare ground, all of which have a negative impact on water recharge of the foothill fescue grassland ecosystems (Johnston 1962, Naeth and Chanasyk 1995).

Several authors suggest that bison spent their summer on the Canadian plains and then moved into the foothills, aspen parklands, and montane valleys such as the Crowsnest Pass (White *et al.* 2001), to avoid harsh winters on the plains (Moodie and Ray 1976, Morgan 1980, Hanson 1984, Chisholm *et al.* 1986, Bamforth 1987, Epp 1988, Kay and White 2001). Some bison may have summered in the mountains, but these non-migratory animals as well as other ungulates would have been under intense predation by Native Americans, wolves, and bears (*Ursus arctos* and *U. americanus*) (Kay *et al.* 1999, Kay and White 2001) and thus kept in low numbers. This would have ensured that fescue grasslands were not grazed heavily during the actively growing season.

With the arrival of the first settlers in the late 1800s, came fire suppression policies (Murphy 1985), reduction of Native American populations through repeated European-introduced epidemics and other colonial processes, their congregation into Indian reservations, the near extirpation of bison through indiscriminate slaughtering and a reduction in the other large herbivores that once roamed the prairies. The main natural processes that were previously responsible for the maintenance of these ecosystems were altered. As a result, woody vegetation started to encroach in some areas of the prairie, allowing limber pine, aspen, and shrub communities to become established (Moss and Campbell 1947, Johnston and Smoliak 1968, Bailey and Wroe 1974, Wright and Bailey 1982). By the 1880's, domesticated cattle were brought in and large ranches started to develop in one of the continent's preferred stock-raising areas (Campbell *et al.* 1998). Although some have argued that domesticated cattle are ecologically equivalent to bison on their former range (Thomas 1991), others have suggested that bison's morphological, physiological, and behavioural characteristics make them better suited to an open

grassland landscape (Wuerthner 1998). Other studies showed their greater mobility on the landscape where they rarely use the same area for more than three days, their apparent lower requirement for water and thus for grazing close to water, their greater capacity to use steeper terrain and higher elevations, and their ability to utilize lower quality forage (Van Vuren 1979, 1983, 2001, Carbyn *et al.* 1993), all result in better distribution of herbivory pressure on grassland and riparian ecosystems grazed by bison than under cattle usage (Wuerthner 1998).

3.5.3. Drought

Periodic droughts are a natural and regular feature and play a key role in the prairie ecosystems (Case and MacDonald 1995, Leavitt and Chen 2001, Campbell 2002, Gauthier *et al.* 2003). Grassland species have adapted to the cycles of drought that characterize the area where they grow. The vegetation response to climatic extremes is highly variable and species specific on the prairies (Ostlie *et al.* 1997). In the Foothills Fescue natural subregion (Figure 2), snowfall is more substantial than in the Mixedprairie, with greater accumulation in late winter and early spring (Achuff 1994). Native grasses of the foothill fescue grasslands are deep rooted and productive and receive the majority of their moisture during the growing season (Achuff 1994, Alberta Prairie Conservation Forum 2003). The dominant species of this subregion include rough fescue (*Festuca campestris*), Idaho fescue (*F. idahoensis*), Parry's oat grass (*Danthonia parryi*), and intermediate oatgrass (*Danthonia californica*), but also include several other grasses and many forbs (Achuff 1994). Rough fescue has a low tolerance to drought (USDA, NRCS 2002). Idaho fescue is a deep-rooted cool season grass that begins growth early in the season when moisture is still abundant and suppresses annual plants by depleting soil moisture and increasing shade (Borman *et al.* 1991, Smoliak *et al.* 2003). It is considered moderately tolerant to drought.

Dendroclimatic reconstruction of annual precipitation in southwestern Alberta from AD 1505 using limber pine (*Pinus flexilis*) showed that drought occurred in 35 of the 487-year study period at intervals of approximately 30-50 years (Case and MacDonald 1995). Intense droughts occurred in the 1610's, 1720's, and 1790's. The most severe droughts in the reconstructed record occurred in the 1790's when six years of that decade were classified as drought years. Droughts of 1918, 1919, and 1922 were the most severe during the instrumental records on the prairies. However, results from this research might underestimate the frequency and severity of droughts on the prairie, as limber pine samples were taken from the Montane natural subregion where the mean annual precipitation is greater than in the nearby Foothill Fescue and Mixedgrass subregions (Achuff 1994).

Paleoenvironmental studies from lake sediments showed that climate trends from the brief historical records are not adequate to represent the full range of climatic variability that have affected the southern Canadian prairies under the relatively stable atmospheric conditions characteristic of the past 2000 years (Lemmen *et al.* 1997, Leavitt and Chen 2001). Droughts on the prairies exhibited cycles characteristic of potential lunar (14-18 years), solar (20-25 years), and oceanic (60-75 years) forces (Leavitt and Chen 2001). In

Alberta, droughts appear to have occurred on 9, 14, 22, and 33 year periods, with pronounced cycles every 100 and 300 years. Leavitt and Chen (2001) determined that droughts as severe as the 1930's or worse occurred on average every 60.5 years and lasted about 12 years. The probability of such drought to occur by 2030 was 44.9%. Ironically, the droughts of the 1930's and 1980's that affected the prairies were among the mildest of the 2000-year record, with most events being more severe and of greater duration (~10 years and up to 40 years) (Lemmen *et al.* 1997, Leavitt and Chen 2001). However, Leavitt and Chen (2001) advised that drought intensity and timing might vary with geographic location.

Leavitt and Chen (2001) also suggest that the impact of global warming over the next 30 years will likely be difficult to isolate from the naturally high variability in drought occurrence, but eventually, it may return the prairies to the higher drought frequencies of the 18th and 19th centuries.

3.6. Natural Processes of the Rocky Mountain Natural Subregions

In the Rocky Mountain landscapes of the SHARP area, much of the variations in vegetation patterns relate to the pattern of climate, soil moisture, elevation, aspect, wind exposure, time of snow melt and natural disturbances such as fire and avalanches. In the Montane natural subregion (Figure 2), Douglas-fir forests dominate the moderate to steep slopes, while open forests of Douglas-fir and limber pine are found on the drier ridge tops. Open limber pine forests dominate the most exposed rock outcrops and eroding slopes. Lodgepole pine forests are also found on the upland sites, while white spruce forests occur on the more mesic fluvial terraces along streams. Open areas are characterized by grasses such as bluebunch wheatgrass (*Agropyron spicatum*), fescue grasses (*Festuca* spp.) and oatgrasses (*Danthonia* spp.) (Achuff 1994).

The lower part of the Subalpine natural subregion (Figure 2) is represented by closed forests of lodgepole pine, Engelmann spruce, and subalpine fir. Lodgepole pine forests can cover extensive areas following fire. At higher elevations, moister sites that have lower incidence of fire are typically covered with Engelmann spruce-subalpine fir forests. In the transition zone with the alpine region, these forests open up and also include whitebark pine (*Pinus albicaulis*) and subalpine larch (*Larix lyallii*) (Achuff 1994). Grasslands are also found at high elevations on steep southerly and westerly aspects of the Front Ranges and are dominated by hairy wild rye (*Elymus innovatus*), June grass (*Koeleria cristata*), and bearberry (*Arctostaphylos uva-ursi*). Disturbed areas such as avalanche paths and post fire patches are dominated by shrubby and herbaceous communities (Achuff 1994). Localized environmental conditions dictate much of the fine-scale pattern of vegetation found in the Alpine natural subregion (Figure 2). Black alpine sedge (*Carex nigricans*) characterize the deep, late-melting snowbeds. Dwarf shrub heath tundra communities dominated by mountain heathers (*Cassiope* spp.) north of the Crowsnest Pass, grouseberry (*Vaccinium scoparium*), and heathers (*Phyllodoce* spp.) are found in moderately deep snowbeds. Exposed areas of shallow snow are dominated by white mountain avens (*Dryas octopetal*), snow willow (*Salix nivalis*), and moss campion (*Silene acaulis*) or kobresia (*Kobresia myosuroides*) communities.

Shallow soil and rocks at the highest elevation are mainly dominated by lichen communities (Achuff 1994).

3.6.1. Fire

Fire has been a key process in determining the structure and composition of forests in the Rocky Mountains ever since the last ice sheet retreated (Alberta Sustainable Resource Development 2001b, Miller 2000, COCEEC 2002). Fire plays a crucial role in creating a mosaic of burned and unburned areas and a pattern of vegetation at various successional stages, providing wildlife with a variety of habitat conditions from which to select food and cover (Lyon *et al.* 2000b). Fire creates snags, circulates nutrients, and allows the development of seral communities of herbs, shrubs, and trees on which many invertebrates, small mammals, birds, and herbivores depend (Arno 2000).

The effect of fire on wildlife in the Rocky Mountain forests is highly variable and is related mainly to the ways it affects habitat (Lyon *et al.* 2000a). The most dramatic habitat alteration occurs in stand-replacing fires (see fire regime below). In crown fires or severe surface fires, the canopy cover is either eliminated or highly reduced and surface vegetation is consumed over much of the area (Lyon *et al.* 2000a). The resources for herbivores and their predator are altered. Stand-replacing fires convert live trees to snags and causes old decayed snags to fall. Fire may also weaken the bark of surviving trees and provide a point of entry for fungi and facilitating decay. Snags provide nesting and roosting habitat for primary excavators such as the pileated woodpecker (Bull and Jackson 1995) and then for secondary cavity users, including birds and mammals (Lyon *et al.* 2000a). Dead wood on the ground provides food and /or shelter for invertebrates, amphibians, reptiles, and small and large mammals, including bears. Fire-killed trees gradually fall on the ground and provide a long-term supply of woody debris. For ten to twenty years much of the biomass is concentrated on the forest floor. In the early stages of post-fire succession grasses and forbs, and shrub and tree saplings establish and increase in biomass, benefiting grazing and browsing ungulates such as elk and mule deer (Lyon *et al.* 2000b). Several fruit-producing shrubs such as buffaloberry (*Shepherdia canadensis*), *Vaccinium* spp., and wild red raspberry (*Rubus idaeus*) are found in fire successional communities, benefiting birds and small mammals (Lyon *et al.* 2000b), as well as providing grizzly and black bears with a rich food source to fatten on prior to denning (Hamer *et al.* 1991, Holcroft and Herrero 1991). As the vegetation structure and composition can take decades, even centuries to resemble the pre-burn forest conditions, stand-replacing fires are likely to result in many if not all bird species to be replaced (Huff and Smith 2000). Insect-eating (e.g. three-toed and black-backed woodpeckers) and seed-eating (e.g. Clarks' nutcracker) species are favoured in the short term (within five to ten years after fire), while species that require a dense closed canopy such as bark and foliage gleaners (e.g. brown creeper and hermit thrush) are negatively affected immediately after fire but recover in the long term as foliage volume increases. In 30 to 50 years after stand-replacing fires, the herb and shrub layer is suppressed by the saplings that become trees, providing nesting habitat for forest interior animals and hiding and thermal cover for ungulates. The structure of the old-growth coniferous forest that later follows provides food, cover, and nest sites for American marten, tree squirrels, birds

such as crossbills, nuthatches, brown creeper, and woodpecker, as well as an excellent cover for ungulates (Lyon *et al.* 2000a).

The natural role of fire can be understood through the concept of fire regime (Brown 2000). Each forest type is associated with its particular fire regime. Different fire regimes have created habitat mosaics resulting in a variety of vegetation types, structures, and ages, and a landscape in all stages of secondary succession (Tande 1979, Arno 1980). Brown (2000) described four "presettlement" fire regime types based on fire severity for the Canada and United States forests:

1. Understory (or surface) – The dominant vegetation is generally not killed and its structure largely unaltered.
2. Stand-replacement (or crown) – All the aboveground parts of the dominant vegetation is killed and its structure altered.
3. Mixed severity – Dominant vegetation is selectively killed based on its relative resistance to fire, or to varied severity between understory and stand-replacement regimes. Mixed severity fires occur in reaction to changes in stand structure, fuel loadings, topography, but more importantly, in weather (Arno 1980, Wright and Bailey 1982). Strong winds and drought conditions, as often occurring in southwestern Alberta, favour crown fires where fuel is adequate, but if conditions moderate, fires tend to creep at the surface (Arno 1980, Wright and Bailey 1982).
4. Nonfire regime – Little or no occurrence of natural fire, as observed at high elevations on northerly and easterly slopes (Tande 1979).

Fire severity varies with vegetation type, fuel, and topography (slope angle, aspect, and elevation) (Tande 1979, Arno 1980, Wright and Bailey 1982). The more mesic vegetation of the subalpine zones have infrequent surface fires and thus tend to accumulate fuel for longer, resulting in more catastrophic but less frequent crown fires during dry conditions (Tande 1979, Wright and Bailey 1982). The more xeric valley-bottoms and open south- and west-facing slopes at low elevations favour more frequent low- to medium- intensity fires that periodically remove fuel accumulation, resulting in multiple-aged forest stands, and ensuring subsequent low intensity fires (Tande 1979, Wright and Bailey 1982).

Some trees have also developed adaptations that may allow them to sustain a fire depending on its severity, which in turn is closely related to weather, fuel loading, size and distribution of fuel, and moisture content of fuel and soil (Wright and Bailey 1982). Characteristics such as thickness of bark, branch density, bud size, needle length, as well as the ability to regenerate vegetatively after fire and the tree size when fire resistance is gained, all contribute to the overall species resistance to fire (Miller 2000). Miller (2000) summarized these characteristics for most ecosystems of the United States and Canada. Among the most resistant tree species in the SHARP Rocky Mountain ecosystems are Douglas-fir and western larch, while Engelmann spruce and subalpine fir are among the least resistant. It has also been hypothesized that some plants and plant communities have evolved flammability characteristics that make them dependent on fire, burning either more often or less often than the non-fire-dependent ones (Mutch 1970, Wright and Bailey 1982). For example, lodgepole pine is considered a fire-dependant species. In the Rocky Mountains, both serotinous (closed, heat-dependant) and non-serotinous (open)-

coned lodgepole pine trees occur. This allows lodgepole pine to regenerate following either low intensity (non-serotinous cones) or high intensity (serotinous cones) fires (Anderson 2003). Moreover, woody debris accumulating in the maturing lodgepole pine forest from the effect of insect and disease outbreaks, past fires, and overmaturity, increase the risks of high intensity fire that will trigger the release of a superabundant seed supply from the serotinous cones (Day 1972, Anderson 2003).

Shrubs and herbs can generally recover from a fire through sprouting to vegetatively recolonize an area (Wright and Bailey 1982). They may have dormant buds found in the tissue of their stolon, root collar, root crown, or rhizomes that can survive a fire, sprout, and regenerate new shoots (Miller 2000). Plants with dormant buds located within the mineral soil are best adapted to survive forest fire, while plants with buds within the duff layer or above it will either be eliminated or reduced by an intense fire (McLean 1969). Forest fire history and ecology is presented below for the main forest types found in the Montane and Subalpine natural subregions (Achuff 1994).

3.6.1.1. Forests of the Montane Natural Subregion: Limber Pine, Douglas-Fir, Lodgepole Pine

Limber pine's natural distribution in Alberta is restricted to the southwestern corner of the province in the Montane natural subregion (Figure 2; Dhir *et al.* 2003). It exists generally as open forest either on ridgetops mixed with Douglas-fir or as pure stands on the most exposed rock outcrops and eroding morainal or colluvial slopes (Achuff 1994). Limber pine communities are usually found in the zone between coniferous forest and prairie in Alberta (Willoughby *et al.* 2003). Little work has been done in Alberta on fire cycles in the limber pine forest. Fire is thought to be infrequent in this kind of habitat where productivity and fuel accumulation are low due to poor soil development, short growing season, and late snow melt (Johnson 2001). However, wildfire in Kananaskis either completely destroyed limber pine stands or had little or no effect (Webster *et al.* 2000). Rapid recolonization following fire was attributed to Clark's nutcracker's (*Nucifraga columbiana*) ability to disperse limber pine seeds from other local populations on post-burn sites. Limber pine may actually benefit from fire suppression. In some areas, limber pine has expanded its range by invading grasslands where it was previously excluded by fire (Kendall 1998).

Frequent surface fires of low to medium intensity and less frequent mixed or severe fires that sometimes crowned under dry and windy conditions characterize the Douglas-fir – lodgepole pine forest of the Montane Subregion (Arno 1980, Wright and Bailey 1982). This fire regime produced a self-perpetuating landscape mosaic of stands of variable structures, ages, densities, and seral stages (Tande 1979, Arno 1980). This vegetation community is thought to have been kept in park-like appearance for centuries through frequent surface fires that burned the understory vegetation, while crown fires promoted the establishment of a dense even-aged lodgepole pine forest (Arno 1980, Wright and Bailey 1982). The mean fire-free interval for a small (50 ha) *Pseudotsuga menziessi – Pinus contorta* stand ranged between about 15 to 35 years among various studies and was on average 18 years around Jasper, with a range of 1 to 66 years (Tande 1979, Arno 1980).

3.6.1.2. Forests of the Subalpine Natural Subregion: Lodgepole pine, Engelmann Spruce X White Spruce – Subalpine Fir, Whitebark Pine Forest Types

Lodgepole pine is considered a fire-dependant species. As noted in the previous section, both serotinous- and non-serotinous-coned trees occur in most stands, but the proportion varies extensively from one geographic area to another (Wright and Bailey 1982, Uchytil 1992). Moreover, woody debris accumulating in the maturing lodgepole pine forest from the effect of insect and disease outbreaks, past fires, and overmaturity, increase the risks of high intensity fires that trigger the release of a superabundant seed supply from the serotinous cones (Day 1972, Wright and Bailey 1982, Uchytil 1992). This gives rise to forests dominated by dense even-aged lodgepole pine (Day 1972).

In Montane forests, lodgepole pine is a seral species with succession progressing toward Douglas-fir on warm dry-mesic sites, and spruce and fir on cool moist sites (Stringer and LaRoi 1970). Lodgepole pine is climax species on some xeric sites (Hnatiuk 1969). But in the lower part of the subalpine zone, lodgepole pine is a seral species leading to the spruce-subalpine fir forest under low frequency fire cycles (Day 1972), or maintaining itself and, as hypothesised by Wright and Bailey (1982), even eliminating climax species from the stand under a relatively frequent fire cycle (100 years), making it essentially the climax species. Pre-Columbian fires in southern Canada were typically frequent low- to medium- intensity regimes in dry-summer areas with a mean fire-free interval varying between 25 to 50 years for this forest type (Arno 1980). The fire-free interval was estimated at 67 years in the subalpine area of the Crowsnest forest (Day 1972), and 27 years in the montane landscape of Jasper, with a range between of 1 - 88 years (Tande 1979).

The spruce of the lower elevation Subalpine Natural Subregion is often an introgressive hybrid between the Engelmann and the white spruce (Achuff 1994). A study of some old growth Engelmann spruce x white spruce – subalpine fir stands in the Crowsnest Forest (now C5 Forest Management Unit) provided insights on the post-fire structure and succession of this forest type (Day 1972). In Day's (1972) hypothesis, a dense even-aged lodgepole pine forest establishes quickly and initially dominates the post-burn area. With its lower seed supply, its greater difficulty to establish after fire, and its inherent slower growth pattern, spruce is less numerous and grows to a quarter of the height of the dominant lodgepole pine. Subalpine fir is destroyed by fire because of its dehiscent cones and thin resinous bark and thus will re-establish itself very slowly from sporadic survivors, which must develop a seeding population before being capable of re-invading the post-burn site. In the second phase of secondary succession (155 years after fire), lodgepole pine, which cannot regenerate beneath its own canopy, begins to decline and the uneven-aged understory of spruce begins to dominate the canopy. Subalpine fir establishes an aggressive all-aged understory. In the old growth phase (255 years after fire), spruce dominates and lodgepole pine dies. The all-aged spruce-fir understory contains four times as many fir as spruce because of its greater competitive advantage in the shade and higher root competition. In the later phase (355 years after fire), lodgepole pine has been completely eliminated from the stand and the uneven- to all-aged subalpine

fir-spruce now occupies the post-burn site. The overstory is still dominated by spruce because of the subalpine fir's early predisposition to disease.

Prior to the establishment of fire protection policies in the early 1900s, fires initiated mainly by electrical storms would have burned an "average" stand of subalpine forest every 67 years in the Crowsnest Forest (Day 1972) and 90 years in Kananaskis Provincial Park (Hawkes 1979) and maintained it in an early seral phase dominated by lodgepole pine. Post 1900s effective fire protection programs are now allowing succession to move toward the later phases (Day 1972).

Forests of the higher Subalpine natural subregion form an ecotone with the treeless Alpine subregion. Pure Engelmann spruce, subalpine fir, whitebark pine, and subalpine larch dominated these open forests in the SHARP area (Achuff 1994). Whitebark pine is a major seral species in this area, and competes with and is replaced by more shade-tolerant species such as subalpine fir and Engelmann spruce (Arno 1980, Howard 2002). Whitebark pine is the potential climax species on high exposed treeline sites and exceptionally dry sites (Howard 2002). Small spot fires or ground fires of low to moderate intensity characterize the upper subalpine area, with the moist north-aspect communities burning less often than the drier south ones. These fires set succession back to the moderately fire-resistant whitebark pine and open up areas for seedling establishment and for the Clark's nutcracker to cache viable whitebark pine seeds (Howard 2002). Tande (1979) found a pre-Columbian mean fire return interval of 74 years on mostly south aspect slopes around Jasper, while Hawkes (1979) found an interval of 153 years in Kananaskis Provincial Park. Based on fire records from the U.S. Forest Service's Northern Region in 1970-1985, Arno (1986) estimated that only one half of one percent of the seral whitebark pine type had burned during this period, for a theoretical fire free intervals of more than 3000 years for an "average" stand. However, whitebark pine seems to be "caught" in a vicious circle where on one hand a lack of fire makes the aging stands more susceptible to pine beetle epidemics and advances succession toward the more shade-tolerant species, and on the other hand, fire favours growth of Ribes shrubs, the alternate hosts for the introduced pathogen white pine blister rust (*Cronartium ribicola*), and thus favors the spread of the rust into the susceptible whitebark pine trees (Howard 2002, Tomback 2003).

In addition to naturally occurring fires in the Rocky Mountain landscapes, there is evidence that fire was also deliberately set by native people as in the nearby grassland areas to promote beneficial vegetative conditions (Murphy 1985). Traditional burning in the Rockies was conducted on selected areas, with low intensity, and targeted grasslands, savannas, and open forests at low elevation and along travel routes (Baker 2000, Heitzmann 2001). These were done in order to facilitate ease of travel, to enhance grazing habitat for horses and game species, and to favour abundance of usable plant species (Heitzmann 2001). However, Baker (2000) argues that Indians were just a small part of a large Rocky Mountain wilderness, with a fire regime in much of the mountains essentially free of human influence for millennia. Dawson (1886 cited in Murphy 1985) further noted that Indians that had not been exposed to Europeans would not willingly destroy their hunting grounds as demonstrated by the lack of burned forests along the

scarcely used (by Europeans) North Kootenay Pass, while those along the Crownest Pass used by white people were entirely destroyed.

Fire frequency in the Rocky Mountains increased from railroad construction and operation, settlements, and careless campers and travelers (Murphy 1985). The Forest Reserves and Park Act adopted in 1911 marked a turning point in the fire control capability on forest reserves, with organized districts and permanent rangers in them (Murphy 1985).

In Waterton Lakes National Park (WLNP) immediately south of the SHARP area, fire scars and fire-initiated age classes sampling revealed that 46 spreading fires occurred between 1633 and 1940 (Barret 1996). On average, they would have occurred every seven years until the early 1900's. Fire in the area decreased substantially during the peak of the little ice age between the 1750's and 1850's, then increased again with the warming and drying of the landscape and the arrival of the settlers.

Since the modern era of fire record keeping by the Alberta Forest Service in 1931 there were nine major (>200 ha) forest fires in the SHARP area. These include the Crowsnest fire in 1931 that burned 2371.2 ha near the Ptolemy and York creeks, Castle River and Pelletier Creek fires that burned respectively 11,678.5 ha and 308.3 ha in 1934, Pass Creek and Dutch Creek fires that burned respectively 28,006 ha and 4149 ha in 1936, Lynx Creek fire that burned 319.9 ha in 1939, the 1982 fire that burned 348.5 ha near Dutch Creek (Delisle and Hall 1987), Cherry Hill fire that burned 2278.8 ha near Lynx Creek in 2000 (Alberta Sustainable Resource Development 2002), and Lost Creek fire that burned a total of 18,966 ha south of Blairmore in 2003 (P. Loewen, pers. comm.).

Suppression of fire has thus affected the natural ecosystems of the SHARP Rocky Mountain landscapes. Effective fire suppression since the beginning of the century has prevented the establishment of any significant new age-classes resulting in a continuous decline in vertical and horizontal heterogeneity in some Rocky Mountain coniferous forests (Tande 1979). The trees in most stands have become older, and often have a buildup of down woody and or ladder material favouring large stand-replacement fires (Arno 2000). This could decrease vegetation diversity on the landscape, and thus reduce values for wildlife habitat, watershed protection, and esthetics (Arno 2000). According to Andison (2000), there are now large quantities of old forest and higher than normal fire danger, with risks that may be as much ecological as they are cultural. The Lost Creek fire that burned 18,966 ha (P. Loewen, pers. comm.) of forest in the SHARP area provided a good example of the consequences of fire suppression policies in Alberta. Dry weather combined with more than 70 years of fuel accumulation on the forest floor since the last forest fire, produced ideal conditions for the biggest and most destructive wildfire in Alberta in 2003. Its impact on the natural ecosystems was likely very significant. Although it burned mostly uninhabited areas, it forced the evacuation of thousands of people, and threatened industries in the Crowsnest Pass.

Timber harvest is a human induced large-scale stand-replacing disturbance that is acting in the SHARP area. It has the potential to reproduce many of the post fire patterns and

maintain variability over the landscape (Lee 1999). A mosaic of disturbed and undisturbed areas can be created over the landscape by retaining trees, snags, downed woody materials, and understory plants. However, current operating regulations restrict the amount and types of residual material left within cutblocks (Lee 1999). A comparison between the most common wildfire residual pattern (< 1% live merchantable timber) and a harvest strategy leaving 5-6% merchantable timber over 28 years of succession indicated that: 1) the greatest differences in forest structure or biodiversity occurred immediately after disturbance, 2) early fire communities could not be replicated by any practical harvest plan, 3) snags, downed wood, understory plant, mammal, and bird communities became increasingly similar over time, 4) common species diversity was similar, but their abundance was different after 28 years of succession, and 5) the retention of most standing material following wildfire provided a source of carbon unavailable in harvest stands (Alberta Research Council 1999).

It is expected that warmer and drier weather conditions accompanying climate change may promote more forest fires in the Prairie Provinces (Natural Resources Canada 2002).

3.6.2. Snow Avalanche

Snow avalanches are common phenomena in the alpine areas of SHARP where the right combination of slope, terrain, weather, and snow composition is met. A snow avalanche can be defined as "a mass of snow moving downslope, which may also contain ice, soil, rocks or other debris" (Fredston and Fesler 1984 cited in Butler 1998 and in Butler 2001). Snow avalanches follow a well-defined path from a source area, through a transportational track, and into a depositional runout zone (Butler 2001). Large avalanches will remove all tall vegetation from their path, leaving an avalanche track that will remain free of tall vegetation if the avalanche cycles are frequent enough. However, major avalanches on forested slopes are much less likely to occur than on unvegetated or grass-covered slopes (Butler 1998).

Distinctive vegetation adapts to those areas where recurring erosional, transportational, and depositional processes of snow avalanches precludes re-establishment of mature forests (Butler 1998). A diversity of disclimax communities of herbs, shrubs, and flexible deciduous trees that can withstand snow-avalanche impact establish. In Waterton Lakes National Park, these included tall-herb meadow communities, Glacier lily (*Erythronium grandiflorum*), cow parsnip (*Heracleum lanatum*) and other umbellifers, *Vaccinium* spp., menziesia (*Menziesia ferruginea*), mountain ash (*Sorbus* spp.), alder (*Alnus viridis*), and willow (*Salix* spp). At the microhabitat scale, a variety of transverse and longitudinal zonations in vegetation types exists as a result of avalanche impact, frequency, length of burial time by snow, competition from surrounding species and other factors (Malanson and Butler 1984, 1986). Because of this diversity of habitat types, a large diversity of animals utilize avalanche path as food sources and shelter at different times of the year. These include the grizzly bear, black bear, coyote, elk, white-tailed deer, mule deer, bighorn sheep, mountain goat, hoary marmot, Columbian ground squirrel, American pika, deer mouse, numerous birds, numerous insects (Butler 1998), and the wolverine (Krajick 1998). This rich ecosystem was also found to be prime habitat for grizzly bear in

early summer in Waterton Lakes National Park (Hamer *et al.* 1991) as well as throughout the summer in the Swan Mountains of Montana (Waller and Mace 1997).

Winter use of avalanche tracks can be hazardous for the animals that use them, but their death means a source of fresh carrion for scavengers such as the wolverine. In fact, avalanche tracks may be their number one winter food source (Krajick 1998). Runout zones also create a matrix of snow-covered boulders and logs that provides ideal denning habitat for this species.

It is expected that the cycle of avalanche will likely increase in alpine areas with climate change as snow precipitation becomes more important (Ryder 1998).

3.6.3. Insect and Disease Outbreaks

Forest disease such as the mountain pine beetle (*Dendroctonus ponderosae*) is a significant force at the landscape level (Logan and Powell 2001). Much of the life cycle of this insect is spent as larvae, feeding in the phloem of host pine trees and eventually killing them. This is a native insect that has co-evolved as an important ecological component of western pine forests (Logan and Powell 2001). By killing the trees, dead material eventually falls on the ground contributing to the amount of fuel accumulating and creating conditions conducive to intense stand-replacing fires (Flathead Transboundary Network 1999). The dead trees that remain standing conduct fire into the canopy, which result in stand-replacing crown fires. This type of fire is actually what some species, as noted earlier, need to reproduce. In the early 1980's, a severe mountain pine beetle infestation attacked the all-pine stands at or near rotation age in the Castle area.

Another disease from an introduced fungus, called the white pine blister rust (*Cronartium ribicola*), affects the five-needled whitebark pine and limber pine in southern Alberta (Parks Canada 2003). Fire suppression and mortality resulting from the blister rust has permitted more competitive species like Engelmann spruce and subalpine fir to successfully replace whitebark pine in several areas. In 1995-1996, a study in northwestern Montana and southern Alberta showed that on average more than a third of the limber pines were dead and 75% of the living ones were affected by blister rust (Kendall *et al.* 1996). It is believed that climate change will increase the magnitude and frequency of these epidemic outbreaks in Canada's forest (Canadian Forest Service 2002).

3.7. Predator-Prey Interactions

Interactions between predators and their prey are a fundamental part of the processes that shape the ecosystems of the world. Predators may affect the distribution and abundance of their prey, which in turn may affect predator population numbers and distribution (Begon *et al.* 1996). Responses by predators to change in prey density are either functional or numerical (Gunson *et al.* 1993). When the number of prey eaten per predator in a specific time is directly proportional to the number of prey available, the

predator response is said to be functional. A numerical response occurs when the predator population increases or decreases with the availability of prey through changes in birth rates, survival, litter size, and dispersal. Both responses can occur simultaneously. However, the extent at which predator and prey populations may affect one another in an open system is difficult to assess and depends on many variables characteristic to predators, prey, and their environment. According to Commission on Life Science (1997), there is no single pattern that dominates predator-prey interactions. Variations in weather, habitat conditions, and behaviour of predators and prey guarantee that the outcome will be varied, difficult to predict, and difficult to interpret.

In Alberta, the gray wolf (*Canis lupus*), coyote (*Canis latrans*), cougar (*Felis concolor*), black bear (*Ursus americanus*), and grizzly bear (*Ursus arctos*), are considered primary predators in terms of their effect on specific ungulate populations. Secondary predators are bobcat (*Lynx rufus*), wolverine (*Gulo gulo*), golden eagle (*Aquila chrysaetos*), and occasionally lynx (*Canada lynx*) (Gunson *et al.* 1993).

3.7.1. Gray Wolf

In Alberta, the gray wolf is an opportunistic predator that feeds on white-tailed deer, mule deer, caribou, moose, elk, mountain goat, bison, and bighorn sheep, and domestic ungulates such as horses, sheep, and cattle (Gunson *et al.* 1993). It will also take other prey species such as beaver, snowshoe hare, and microtines when available (Gunson *et al.* 1993). Wolves can have an important impact on their prey population. A study of wolf population dynamics and prey relationships in northeastern Alberta revealed that one wolf pack consumed annually about 15% of the moose (mostly yearling and older individuals) in their territory, whereas recruitment was estimated at 19% (Fuller and Keith 1980).

In the SHARP area and across its range, the gray wolf was likely the main factor limiting ungulate populations prior to European arrivals (Mech 1981). Reports from early European explorers indicate that wolves were widespread and abundant in the prairies and foothills until at least the 1870s, and probably occurred at lower densities in the mountains and northern forests (Gunson 1983). The years that followed saw the systematic elimination of prey populations of bison, the reduction of other native prey ungulates through market hunting and severe winter weather, and the strychnine poisoning of wolves for their pelts. By 1890, wolf populations were drastically reduced in the prairie portion of Alberta (Gunson 1983). Concurrently, beef cattle were brought into "Alberta" from the United States and provided wolves with an alternative prey species, but also carrying diseases that would further impact native ungulate populations (Gibbard and Shepard 1992). In 1899, wolf depredation on cattle prompted ordinances from the government to establish a wolf bounty in what is now southern Alberta to be paid through the Western Stock Growers Association (Alberta Fish and Wildlife Division 1991). By the 1900s, wolves were considered scarce along the eastern slopes of the Rockies and practically inexistent in the Prairies (Stelfox 1969 cited in Gunson 1983). Cowan (1947) indicated that gray wolves used to be fairly common around Waterton Lakes Park until 1921 when a "wolfer" was employed by cattlemen following increased depredation on

domestic livestock. As a result, wolves were locally extirpated and did not reappear until 1943. In 1944, two black wolves were present in the area, but the male was shot at a beef carcass in the park (Cowan 1947). Until the 1970's, only lone wolves were rarely detected anywhere in Waterton Lakes Park and vicinity, and because of this scarcity, ungulate predation by wolves had been insignificant in the area (Soper 1973). In other parts of the province, moderate increase in ungulate numbers and relaxed persecution allowed wolves numbers to bounce back. However, public perceptions relating to livestock depredation, rabies, and adverse effects on ungulate populations triggered a second wave of predator control in the 1950s (Gunson *et al.* 1993). In the late 1960s – early 1970s, wolf populations increased again in the province and their range expanded south along the western mountains and foothills (Gunson 1983). In 1976, a pack of nine wolves was observed near the south end of the Livingstone Range in the SHARP area. Six of them were poisoned following depredation on cattle (Cole *et al.* 1977, Gunson 1983). This range expansion did not continue during the 1977-1981 period and the most southerly range occupied by a pack of actively reproducing wolves was at the northwest branch of the Oldman River from 1977-1979 (Gunson 1983). Following an analysis of sightings in the Livingstone and Porcupine area and field research near the Oldman River in the early 1980s (Harris 1981, 1982), Ream and Harris (1986) suggested that the trapping and hunting regulations in the province contributed to the low wolf population in the area.

Most recently, satellite telemetry data gathered on wolves in three packs during the winter of 2004, combined with sighting and occurrence data strongly suggest that at least during the early and mid season, stable packs (i.e. groups larger than five that occupied distinct and separate territories) were present from the southern to northern boundary of the SHARP area. This is the first time in recent decades that distribution has been continuous and, at least for the short term, stable in the area. Moreover, these territories appeared to be in alignment with winter elk distribution. Two of these packs have been linked to ongoing cattle depredation, however, and their future is uncertain. One pack numbering 14 in the late summer 2003 has been reduced by agency staff and by landowners and private hunters to two individuals. These remaining two wolves continue to occupy the same territory, but continue to depredate livestock. Prey populations continue at strong levels, so competition with hunters by wolves is minimized. However, cattle depredation issues continue to be the focus of improved management techniques (C. Bergman, pers. comm.).

As wolves re-establish in the area, the eastern slopes of the SHARP area represent an important north-south travel and dispersal corridor for wolf movement between Jasper and Yellowstone national parks and for the connectivity with populations south of the U.S. border (Ream and Harris 1986, U.S. Fish and Wildlife Service 1987, Boyd *et al.* 1995).

3.7.2. Coyote

Prior to settlement, coyotes were uncommon in the prairies (Banfield 1974, Pattie and Fisher 1999), possibly due to the antagonistic behaviour of the gray wolf (Fuller and Keith 1981, Carbyn 1982) that reduced their abundance and distribution (Mech 1981).

The coyote is one of the few mammals that have been able to adjust to human settlement and live in proximity of farms and towns (Banfield 1974). With the decrease in wolf numbers and range, the expansion of agriculture, and deforestation, coyotes have increased in abundance and distribution in Alberta and throughout the continent (Nowak 1978). They are now common throughout the entire province (Smith 1993). Coyotes are also opportunistic feeders and will forage on vertebrate animals, invertebrates, berries, and other plant items (Todd *et al.* 1981, Voigt and Berg 1987). Predation on ungulates does occur, but carrion remain their primary food source throughout the year (Gunson *et al.* 1993). Because of their small size, coyotes tend to prey on mice, vole, hares, ground squirrels, and other small mammals and birds, but predation on wild ungulates directed toward neonates, or on larger adults involving cooperative hunting by a group of coyotes also takes place (Gunson *et al.* 1993). In some local situations, Gunson *et al.* (1993) mentioned that coyote predation affected ungulate populations, but in general this was not the case in Alberta. Severe effects on ungulate populations can occur when disease, and reduced habitat quality resulting from extreme weather conditions or human alteration, act cumulatively with coyote predation.

3.7.3. Grizzly Bear and Black Bear

Grizzly bears are opportunistic omnivorous animals whose diet varies considerably from being almost completely vegetation-based to almost completely animal-based (Alberta Environmental Protection 1997). In Jasper, Banff, and Waterton Lakes national parks, the primary food item taken in spring and fall was roots of *Hedysarum* spp. (Russell *et al.* 1979, Hamer and Herrero 1983, Hamer *et al.* 1991). In early spring, they also scavenged on winter-killed or preyed on winter-weakened ungulates. As green vegetation sprung up, grizzly bears switched their diet to available succulent forbs such as common horsetail (*Equisetum arvense*), cow parsnip (*Heracleum lanatum*), mountain sorrel (*Oxyria digna*), angelica (*Angelica* spp.), and Glacier lily (*Erythronium grandiflorum*). Ground squirrels (Columbian – *Spermophilus columbianus* and golden mantled – *S. lateralis*) were also consumed at various levels in mid-summer (Russell *et al.* 1979, Hamer and Herrero 1983). In late summer and throughout the fall, berries, such as buffaloberry (*Shepherdia canadensis*), common bearberry (*Arctostaphylos uva-ursi*), crowberry (*Empetrum nigrum*), gooseberry (*Ribes* spp.), as well as *Vaccinium* spp. made up the main components of the grizzly bear's diet during this pre-denning fattening period (Hamer and Herrero 1983, Kansas and Riddell 1995).

Grizzly bear predation on ungulates can be important in some areas. In southcentral Alaska, Ballard *et al.* (1981) determined that the 79% of the marked moose calves that died naturally had been killed by brown bears (grizzly). In the Rocky Mountains of Alberta, grizzly bear predation on ungulates appeared particularly important in the spring when they killed winter-weakened individuals, neonates, birth-weakened adult females, but also took place in the fall on rut-weaken adult males, and opportunistically throughout the bear's active period (Russell *et al.* 1979, Hamer and Herrero 1983, Hamer and Herrero 1991). However, the extent of predation by grizzly bears on ungulate populations and how this process affects prey populations have received little attention in the SHARP area and much of Alberta.

In the early 1700s, grizzly bears were abundant and were more common than black bears in much of the prairies and the open foothills east of the Rocky Mountains (Thompson 1962), especially along river systems where abundance of suitable food such as berries, roots, carcasses of drowned bison, and watering ungulates were found (Nielsen 1975). However, this may reflect the fact that early explorers used river systems to travel and that is mostly where historical records are found. Ground squirrels were one of their important prey items (Alberta Environmental Protection 1997) and thus, grizzly bears probably moved around in response to food availability. Very few grizzly bears were hunted by native people because of the difficulty and the risks involved in hunting such a large animal and because of their spiritual beliefs (Nielsen 1975).

By the 1800s, the natural role of the grizzly bear on the prairie and open foothills was altered by the arrival of increasing numbers of fur traders, explorers, surveyors, and settlers in Alberta. The grizzly bear was shot for the fear it conveyed, for livestock protection, for sport and for its hide (Alberta Fish and Wildlife Division 1990). Its demise followed the pattern of land settlement. By the 1880s, the grizzly bear was essentially extirpated from southern Alberta where it had been most numerous (Nielsen 1975) and by the 1890s, sightings east of the Rocky Mountains were unusual (McDougal 1971). In the early 1900s, the three mountain national parks (Jasper, Banff, and Waterton Lakes) provided a refuge to the remaining population. Ranchers, established on the land adjacent to those parks, prevented the bears from dispersing into the foothills and the prairies (Nielsen 1975).

Black bears are also opportunistic omnivores that take a variety of food items such as succulent early growth stage of plants, insects, animal carrion and prey (Pelton 1982, Kolenosky and Strathearn 1987, Holcroft and Herrero 1991).

In the foothills of the Rocky Mountains, just north of the SHARP area, scat analyses revealed that black bears in spring fed primarily on green vegetation (pea vine, wild vetch, dandelion, and several other forbs), but also on overwintered common bearberry, grass, mammals, and ants (Holcroft and Herrero 1991). In early summer, green vegetation, including cow parsnip and hedysarum, was the primary food. Ants were commonly taken and buffaloberry was used later during that period. In late summer, wild raspberry (*Rubus idaeus*) was the primary food item. Buffaloberry, ants, and *Vaccinium* spp. were also common, but green vegetation intake decreased and other available berries as well as horsetail and mammals were used minimally. Fall food appeared to be composed mainly of bearberry, bog cranberry, wasps, mammals, and green vegetation. Prickly rose, grass, cow parsnip, wild red raspberry were also taken. Mammal prey in the fall may have included injured animals and carcasses left by hunters (Holcroft and Herrero 1991).

Black bears are known to prey on ungulates (Verspoor 1983, Kolenosky and Strathearn 1987, Matthews and Porter 1988, Gunson *et al.* 1993). This has been documented as an important mortality factor influencing several populations of wild ungulates in North America (Franzmann *et al.* 1980, Wilton *et al.* 1984, Hamer and Herrero 1991). The scat study in Kananaskis country revealed that various species of ungulates were taken by

black bear throughout the year, but they did not appear to represent an important dietary component in that region, although the authors warned that scat volumes likely underestimated volumes consumed because of the greater digestibility of meat (Pritchard and Robbins 1990, Holcroft and Herrero 1991). Likewise, black bear predation on ungulate populations in the SHARP area probably occurs but is likely unimportant.

Black bears are forest-dwellers and were not common in southern Alberta, which was the grizzly bear domain when the first Europeans arrived (Alberta Environmental Protection 1997). They were more abundant in the wilderness of the north and were not impacted as much by the increasing human presence to the south.

Not until 1927 did both grizzly and black bears in the province receive a legal status. This afforded some level of protection through bag limits and selective hunting, and the following year, a closed harvest season (Alberta Fish and Wildlife Division 1990). However, this did not apply for a large part of the SHARP area where an open season on all bears was established in 1928 for the area "south of the Crow's Nest Branch of the Canadian Pacific Railway (CPR) and west of the fifth meridian" (excluding the Crow's Nest forest Reserve and Waterton Park) where bears had caused damage to livestock (Alberta Fish and Wildlife Division 1990). The following year, the eastern boundary of this area was expanded further east to the beginning of range 27, west of the fourth meridian.

Both bear species in the province were believed to be increasing in numbers during the 1930s and early 1940s. Black bears were of particular concern because of their depredation on cattle. As a result, the province removed all legal protection for both bear species in 1944, except within the extent of Forest Reserves where the grizzly bear was still legally protected (Alberta Fish and Wildlife Division 1990). Legal protection for the black bear was reinstated in the Rocky Mountain Forest Reserve in 1947. In 1948, grizzly bears were still considered predatory animals and could be hunted anywhere in southern Alberta, south of the Medicine Hat-Crowsnest CPR branch. Hunters were also hired by the government to kill them in the Forest Reserves and the Waterton-Carbondale Game Preserves (Alberta Fish and Wildlife Division 1990).

Indiscriminate trapping and killing of bears in settled areas and poisoning through the early 1950s anti-rabies programs targeted at wolves and coyotes contributed to the dramatic decline in bear populations in the western foothills and other northern habitats during the 1950s (Alberta Fish and Wildlife Services 1993, Alberta Environmental Protection 1997). In 1953, spring bear licenses were introduced (Alberta Fish and Wildlife Service 1993). In 1961, the province tightened its application conditions for nuisance bear permits, but not until 1968 was a grizzly license introduced. In 1970, the fall grizzly bear season was removed and compulsory kill registration was initiated for the species (Alberta Fish and Wildlife Division 1990). Black and grizzly bear populations responded to reduced kills in the 1970s and improved bear habitat resulting from logging and other natural resource extraction activities (Alberta Fish and Wildlife Services 1993, Alberta Environmental Protection 1997). However, the structure of the grizzly bear population in southwestern Alberta is currently believed to follow a source-sink model,

where parks are considered sources and areas near human facilities are considered sinks (Alberta Fish and Wildlife Division 1990). A hair capture, DNA profiling, and mark-recapture analysis conducted in southwestern Alberta and southeastern British Columbia in 1996-1997 revealed that an estimated 74 (95% CI = 60-100) grizzly bears were present in the SHARP area and Waterton Lakes National Park (Mowat and Strobeck 2000).

3.7.4. Cougar

Cougars prey primarily on adult and neonate ungulates (Spalding and Lesowski 1971, Toweill 1977, Ackerman *et al.* 1984, Alberta Fish and Wildlife Division 1992, Ross and Jalkotzy 1992). In the Rocky Mountains and foothills of Alberta, in the Sheep River area, ungulates represented 90% of over 200 winter kills discovered between 1981 and 1991 (Gunson *et al.* 1993). In this study, cougars preyed largely on mule and white-tailed deer, moose, elk, and occasionally on bighorn sheep. Other prey included beaver (*Castor canadensis*), porcupine (*Erethizon dorsatum*), coyote, snowshoe hare (*Lepus americanus*), grouse (*Dendragopus canadensis*, *Bonasa umbellus*), and domestic dog (*Canis familiaris*). Analyses of stomach contents from hunter-killed cougars in the province revealed that 69% contained cervids, primarily mule deer. Biomass data showed that 39% of meat consumed was from mule and white-tailed deer, while moose represented 33%, and elk 25% (Gunson *et al.* 1993). Both sexes in all age classes of mule deer were taken, while only moose calves, and elk calves and cows were selected. This possibly reflects the greater ease of cougars at taking smaller ungulates and the greater difficulty and risk associated with preying on larger animals with hooves and antlers (Gunson *et al.* 1993).

Cougars are probably an important source of mortality to ungulate populations in the foothills and mountains of the SHARP area and southwestern Alberta (Gunson *et al.* 1993). However, the extent of this is unknown, and in the only cougar study in the province, consumption rates were not determined (Alberta Fish and Wildlife Division 1992). Despite the fact that cougar habitat in the SHARP area is limited, it is considered the best in the province and cougars are relatively abundant. Prey species such as deer and elk enjoy better habitat, milder winters, lower snow accumulations and thus greater densities than further north (Alberta Fish and Wildlife Division 1989, Alberta Natural Resources Service 1995). Cougar density estimates vary between 4.0 cougars/100 km^2 in the foothills to 3.5 cougars/100 km^2 in the mountains along the continental divide (Alberta Fish and Wildlife Division 1992).

Historically in Alberta, the cougar was found across the Rocky Mountains and foothills up to Grande Prairie, and in some areas within the South Saskatchewan River drainage to the east, with sightings as far east as the Cypress Hills (Alberta Fish and Wildlife Division 1992). The northerly limit of occurrence since 1982 has been east to Lac La Biche and Cold Lake, and west to Peace River and the Clear Hills (Alberta Fish and Wildlife Division 1992).

Estimates of population levels in historic times are mainly conjectural (Alberta Fish and Wildlife Division 1992). Cougar were seldom seen or hunted (Soper 1964). However, the

reduction of native prey ungulate populations in southern Alberta at the end of the 1800s (see section on gray wolf) likely negatively affected cougar populations as well (Alberta Fish and Wildlife Division 1992). Their numbers are believed to have increased again as ungulate numbers rebounded during the first half of the 1900s. A bounty was introduced for cougars on provincial land in Alberta between 1937 and 1964. Records of bounty cougars between 1949 and 1962 showed that twice as many cougars had been killed from the Sundre district north, as from the Morley district south. This may reflect a greater harvest effort to the north, but prey ungulate species such as elk were also more abundant in the northern mountain and foothills in the 1950s (Alberta Fish and Wildlife Division 1992). The first cougar season in Alberta was declared in 1969 when they could be hunted under an elk, moose, or deer license. Not until 1971 was cougar officially designated a "big game animal" and that a license for cougar hunting was introduced (Alberta Fish and Wildlife Division 1992).

3.7.5. Wolverine

The wolverine is an opportunistic feeder, varying from being mainly scavenger in winter, to being primarily predator during the summer months. The most common prey of the wolverine include marmots, ground squirrels, mice, voles, birds and insects (Petersen 1997). In winter, they rely heavily on carrion of large ungulates that have been killed by other predators or that have died of disease or starvation. They may supplement their winter diet with smaller prey such as porcupine, mice and voles (Petersen 1997). In addition, they are known to have killed large ungulates such as caribou and moose in deep snow and when ungulates are vulnerable (Banci 1994). In a Montana study, mule deer and elk were the primary ungulates in the diet of wolverines (Hornocker and Hash 1981). A large population of ungulates and the presence of large carnivores such as grizzly bears, wolves, and cougars that will provide a sufficient amount of carrion, are important for the survival of the wolverine (Petersen 1997, COSEWIC 2003). However, these carnivores compete with wolverines at kill sites, and are also a potential source of wolverine mortality (COSEWIC 2003).

Historically, the wolverine was found throughout Alberta in a wide variety of habitats (Petersen 1997). The large reductions in the ungulate prey populations by early settlers in the late 1800s is thought to have contributed to the reduction of the wolverines' range (Dauphine 1989). Although available inventory methods for estimating wolverine abundance were reviewed by Mowat (2001) and some hair sampling methods were tested in the field (Mowat *et al.* 2003), no accurate wolverine population estimates are currently available in Alberta (Petersen 1997, COSEWIC 2003). Harvest data show that wolverines do occur in the SHARP area (Petersen 1997, Poole and Mowat 2001), but their abundance and impact on prey populations are unknown.

In the late 1870's elk populations in southwestern Alberta suffered from a major die-off believed to have been caused by a cattle-borne bacteria to which they had not previously been exposed (Gibbard and Sheppard 1992). At the end of the 19th century, bison, grizzly bears, and wolves were all extirpated from the prairies.

It is evident that the arrivals of the Europeans introduced new variables in the natural processes that regulated population numbers. The century that followed saw game and fur species management regulating when and how wildlife should be taken and exert a certain level of control over populations of predator and prey species. Control was and is still to some extent biased against predator species.

4.0 CONCLUSION

The headwaters region of the Oldman River Basin in southwestern Alberta is comprised of a rich mosaic of habitats that support an important diversity of species and plant communities. Natural processes are essential at maintaining the ecological integrity of this landscape and at ensuring the conservation and the long-term sustainability of this biodiversity. The area is also home to a large number of species at risk, sensitive species, and species of unknown status for which adequate knowledge is lacking. With increasing demand for natural resources and increasing human activities in the area, habitats are quickly being transformed and some of the natural processes are being altered. As a result, several species are now threatened with extirpation from the area, and others are facing decreasing population numbers.

The multi-species approach presents a practical and innovative way of promptly implementing conservation initiatives for a potentially large number of species at risk and possibly other non-threatened elements of biodiversity. This approach was first applied in Alberta in the Milk River Basin area (Quinlan *et al.* 2003). It proved to be useful and feasible on a drainage-basin landscape. Because of the number species at risk present in the area and because of the threats on the landscape, the Alberta Fish and Wildlife Division and the Alberta Conservation Association decided to apply this concept to the headwaters region of the Oldman River Basin. The first year of the project was aimed at 1) determining the key natural processes taking place in the Southern Headwaters At Risk Project area, 2) identifying the species at risk present, 3) selecting a group of focal species whose habitat would be most representative of that of a majority of species at risk, 4) assessing information gaps on those focal species in the area, 5) conducting surveys to fill these gaps, 6) determining their habitat associations and developing habitat suitability index (HSI) models, and 7) mapping HSI models to determine areas of greatest habitat potential for each focal species. Volume one introduced the project and presented the key natural processes in the area. Volume two (Blouin *et al.* 2003) provided the list of species at risk occurring in the SHARP area, the focal species selection process, the focal species HSI models and their associated habitat potential maps.

In the next phase of this project, the habitat potential maps will be overlaid to determine landscape "hot spots", considered highly suitable for a group of focal species and potentially suitable for a suite of species at risk. A landscape management map showing variable management priority units will be developed for the SHARP area. Landscape-level threats and pressures will be identified and analyzed to determine their impact on the natural processes identified in this volume and their effect on the spatial, compositional, and functional requirements of focal species. Priority landscape management units will be targeted for the development of cooperative habitat

stewardship programs. Management guidelines will be developed or recommendations will be made to stakeholders as to how current management practices or land use guidelines could be improved to mitigate or remove landscape threats and pressure and ensure the maintenance of natural processes and the conservation and sustainability of species at risk.

5.0 LITERATURE CITED

Achuff, P.L. 1994. Natural regions, subregions and natural history themes of Alberta: A classification for protected areas management. Report No.2. Prepared for Parks Services and Natural and Protected Areas, Alberta Government. 72 pp.

Ackerman, B.B., Lindzey, F.G., and T.P. Hemker. 1984. Cougar food habits in southern Utah. J. Wildl. Manage. 48: 147-155.

Ahlenslager, K. E. 1987. *Pinus albicaulis. In*: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (2002, April). Fire Effects Information System, [Online]. Available: http://www.fs.fed.us/database/feis/. [Accessed 2003 September 8].

Alberta Environment. 1993. Focus on water quality. *In*: Oldman River Basin Water Quality Initiative 2002. Oldman River Basin Water Quality and Land Use Interactive Map and Data CD, Version 1.0. [CD-ROM]. Lethbridge, AB.

Alberta Environment 1999. Reservoir Lands Guideline. Natural Resources Service, Water Management Division. Pub. No. I/875. 7 pp.

Alberta Environment. 2003. Alberta's River Basins. http://www3.gov.ab.ca/env/water/basins/BasinForm.cfm. [Accessed 2003 August 13].

Alberta Environmental Protection. 1996. Alberta State of the Environment Report: Aquatic Ecosystems. Alberta Environmental Protection Pub. No I/674. Edmonton, AB. 144 pp. + appendices.

Alberta Environmental Protection. 1997. Bears in Alberta : their characteristics, history, behaviour and management. Alberta Environmental Protection, Natural Resources, Pub. No. I/646. Edmonton, AB. 24 pp.

Alberta Fish and Wildlife Division. 1989. Management plan for grizzly bears in Alberta. Wildlife Management Planning Series No. 1. Forestry, Lands and Wildlife, Pub. No. T/204. Edmonton, AB. 121 pp.+ appendices.

Alberta Fish and Wildlife Division. 1990. Management plan for grizzly bears in Alberta. Wildlife Management Planning Series No. 2. Forestry, Lands and Wildlife, Pub. No. T/232. Edmonton, AB. 164 pp.

Alberta Fish and Wildlife Division. 1991. Management plan for wolves in Alberta. Wildlife Management Planning Series No. 4. Forestry, Lands and Wildlife Pub. No. T/237. Edmonton, AB. 89 pp.

Alberta Fish and Wildlife Division. 1992. Management plan for cougars in Alberta. Wildlife Management Planning Series No. 5. Forestry, Lands and Wildlife Pub. No. T/243. Edmonton, AB. 91 pp.

Alberta Fish and Wildlife Services. 1993. Management plan for black bears in Alberta. Wildlife Management Planning Series No. 10. Environmental Protection, Pub. No. T/276. Edmonton, AB. 116 pp.

Alberta Natural Resources Service. 1995. Management plan for white-tailed deer in Alberta. Wildlife Management Planning Series No. 11. Environmental Protection, Pub. No. T/303. Edmonton, AB. 119 pp. + appendices.

Alberta Prairie Conservation Forum. 2003. What is prairie? Available: http://www.albertapcf.ab.ca/what_is_prairie.htm. [Accessed 2003 September 18].

Alberta Research Council. 1999. Fire and Harvest Residual (FAHR) Project: The impact of wildfire and harvest residuals on forest structure and biodiversity in aspen-dominated boreal forests of Alberta. Alberta Environment Pub. No. T/495. Edmonton, AB. 11 pp. Available: http://www.abmp.arc.ab.ca/AnnualReport2003.pdf . [Accessed 2004 March 11].

Alberta Resource Evaluation and Planning Division. 1985. Castle River sub-regional integrated resource plan. Alberta Energy and Natural Resources, Edmonton, AB. 113 pp.

Alberta Soil Information Centre. 2001. AGRASID 3.0: Agricultural Region of Alberta Soil Inventory Database (Version 3.0). Edited by J.A. Brierley, T.C. Martin, and D.J. Spiess. Agriculture and Agri-Food Canada, Research Branch; Alberta Agriculture, Food and Rural Development, Conservation and Development Branch. http://www.agric.gov.ab.ca/soil/agrasid/agrasidmainpage.html. [Accessed 2003 July 17].

Alberta Sustainable Resource Development. 2001a. The general status of Alberta wild species 2000. Alberta Sustainable Resource Development, Fish and Wildlife Service. Pub No I/023. Edmonton, AB. 46 pp.

Alberta Sustainable Resource Development. 2001b. Wildfire Management in Alberta. Publication Number 1/857. Edmonton, AB. 24 pp.

Alberta Sustainable Resource Development. 2002. Historical Spatial Wildfire Data, Historical Wildfire Information. http://envweb.env.gov.ab.ca/env/forests/fpd/hwiwp.html. [Accessed 2003 September 12].

Anderson, M.D. 2003, July. *Pinus contorta* var. *latifolia*. *In*: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/. [Accessed 2004 January 27].

Anderson, H.G., and A.W. Bailey. 1980. Effects of annual burning on vegetation in the aspen parkland of east central Alberta. Can. J. Bot. 58: 985-996.

Andison, D.W. 2000. Natural sub-regions: are they meaningful? Foothills Model Forest Natural Disturbance Program Research, Quicknote No. 2 – May 2000. 1 p.

Anonymous. 1997. Bugs and diseases – info note. Alberta Environmental Protection. Edmonton, AB. 6 pp.

Anonymous. 2002. What is climate change: the science behind the story. Government of Canada web site: http://climatechange.gc.ca/english/issues/what_is/index.shtml. [Accessed 2003 March 31].

Apps, C.D. 1997. Identification of grizzly bear linkage zones along the Highway 3 corridor of southeast British Columbia and southwest Alberta. British Columbia Ministry of the Environment, Lands and Parks and World Wildlife Fund Canada and U.S. Aspen Wildlife Research, Calgary, AB. 45 pp.

Arno, S.F. 1980. Forest Fire history in the Northern Rockies. J. For. 78: 460-465

Arno, S.F. 1986. Whitebark pine cone crops--a diminishing source of wildlife food? Western Journal of Applied Forestry. 3: 92-94.

Arno, S.F. 2000. Fire in western forest ecosystems. Pp 97-120 *in* Brown, J. K., and J. Kapler Smith (eds). Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Arthur, G.W. 1975. Introduction to the ecology of early historic communal bison hunting among the Northern Plains Indians. Archaeol. Surv. of Can. Pap. 37. National Museum of Manitoba, Mercury Series. National Museums of Canada. Ottawa. 136 pp.

Ashmore, P., and Church, M. 2001. The impact of climate change in rivers and river processes in Canada; Geological Survey of Canada, Bulletin 555. 58 pp.

Bailey, A.W., and M.L. Anderson. 1978. Prescribed burning of Festuca-Stipa grassland. J. Range Manage. 31: 446-449.

Bailey, A.W., and R.W. Wroe. 1974. Aspen invasion in a portion of the Alberta Parklands. J. Range Manage. 27: 263-266.

Baker, W. L. 2002. Indians and fire in the Rocky Mountains: The wilderness hypothesis renewed. p. 41-76 *in* Vale, T.R. (ed). Fire, native peoples, and the natural landscape. Island Press, Washington, D.C.

Ballard, W.B., Spaker, T.H., and K.P. Taylor. 1981. Causes of neonatal moose calf mortality in south central Alaska. J. Wildl. Manage 45: 335-342.

Bamforth, D.B. 1987. Historical documents and the bison ecology on the Great Plains. Plains Anthropologist 32: 1-15.

Banci, V. 1994. Wolverine. Pp. 99-127 *in* Ruggiero, L.F., K.B. Aubry, S.W. Buskirk, L.J. Lyon, and W.J. Zielinski (eds.). The scientific basis for conserving forest carnivores: American marten, fisher, lynx, and wolverine in the western United States. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station GTR-RM-254. Fort Collins, CO.

Banfield, A.W.F. 1974. The mammals of Canada. University of Toronto Press, Toronto, ON. 438 pp.

Barrett, S.W. 1996. The historical role of fire in Waterton Lakes National Park, Alberta. Unpublished report for Parks Canada. 32 pp + maps.

Barret, S.W., and S.F. Arno. 1982. Indian fires as an ecological influence in the northern Rockies. J. Forestry. 80: 647-651.

Beaty, C.B. 1975. The landscapes of Southern Alberta: A regional geomorphology. The University of Lethbridge Printing Services, Lethbridge, AB. 95 pp.

Begon, M., Harper, J.L., and C.R. Townsend. 1996. Ecology – individuals, populations and communities. 3rd ed. Blackwell Science Ltd., Cambridge, MA. 1068 pp.

Blouin, F., Taylor, B.N. and R.W.Quinlan (eds). 2004. The Southern Headwaters At Risk Project: A multi-species conservation strategy for the headwaters of the Oldman River. Volume 2: species selection and habitat suitability index models. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 90, Edmonton, AB.

Borman, M.M., Krueger, W.C., and D.E. Johnson. 1991. Effects of established perennial grasses on yields of associated annual weeds. J. Range Manage. 4: 318-322.

Boyd, D.K., Paquet, P.C., Donelon, S., Ream, R.R., Pletcher, D.H., and C.C. White.1995. Transboundary movements of a recolonizing wolf population in the Rocky Mountains. Pp. 135-140 *in* L.N. Carby, S.H. Fritts and D.R. Seip (eds). Ecology and conservation of wolves in a changing world. Canadian Circumpolar Institute, Occasional Publication No. 35. Edmonton, AB.

Bradley, C., and C. Wallis. 1996. Prairie Ecosystem Management: An Alberta perspective. Prairie Conservation Forum, Occasional Paper Number 2, Lethbridge, AB. 29 pp.

Bradshaw, D.A., Saxena, A., Enns, L.K., Schultz, R., and M. Sherrington. 1997. Biophysical inventory, significant, sensitive and disturbance features of the Whaleback area. Prepared for Resource Data Division, Alberta Environmental Protection. Geowest Environmental Consultants Ltd. Edmonton, AB. 107 pp. + appendices.

Brown, J.K. 2000. Introduction and fire regimes. Pp 1-8 *in* Brown, J. K., and J. Kapler Smith (eds). Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Bull, E.L., and J.E. Jackson. 1995. Pileated woodpecker (*Dryocopus pileatus*). *In*: The Birds of North America, No. 148 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, D.C. 24 pp.

Butler, D.R. 1998. Teaching natural hazards: the use of snow avalanches in demonstrating and addressing geographic topics and principles. J. of Geography 87: 212-225.

Butler, D.R. 2001. Geomorphic process - disturbance corridors: a variation on a principle of landscape ecology. Prog. in Phys. Geog. 25: 237-248.

Campbell, C. 2002. Late Holocene lake sedimentology and climate change in southern Alberta, Canada. Quaternary Research 49: 96-101.

Campbell, C., Stubbs, L.S-G., Schroeder, J., Sweeney, S., and M. Moosberger. 1998. Agriculture in the Prairie Provinces. On the University of Manitoba Archives & Special Collections's web site https://www.umanitoba.ca/libraries/units/archives/agric_exper/history.html. [Accessed 2003 March].

Canadian Forest Service. 2002. Climate change and fire and insect disturbances in Canada's forests. CFS web site: http://www.nrcan.gc.ca/cfs-scf/science/brochure_climate_fire/intr_e.html. [Accessed 2003 March 31]

Carbyn, L.N.1982. Coyote population fluctuations and spatial distribution in relation to wolf territories in Riding Mountain National Park, Manitoba. Can. Field Nat. 96: 176-183

Carbyn, L.N., Oosenbrug, S.M., and D.W. Anions. 1993. Wolves, bison, and the dynamics related to the Peace-Athabasca Delta in Canada's Wood Buffalo National Park. Circumpolar Research Series No. 4, Canadian Circumpolar Institute, University of Alberta, Edmonton, AB. 270 pp. + appendices.

Case, R. A., and G. M. MacDonald. 1995. A Dendroclimatic reconstruction of annual precipitation on the Western Canadian Prairies since A.D. 1505 from *Pinus flexilis* James. Quaternary Research 44: 267-275.

Chetner, S., and the Agroclimatic Atlas Working Group, 2003. Agroclimatic Atlas of Alberta, 1971 to 2000. Alberta Agriculture, Food and Rural Development, Agdex 071-1. Edmonton, Alberta. Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6295?OpenDocument . [Accessed 2003 March 31].

Chisholm, B., J. Driver, S. Dube, and H.P. Schwarcz. 1986. Assessment of prehistoric bison foraging and movement patterns via stable-carbon isotopic analysis. Plains Anthropologist 31: 1993-205.

COCEEC (Crown of the Continent Ecosystem Education Consortium). 2002. Crown of the Continent: profile of a treasured landscape. First edition. Scott Publishing, Kalispell, MT. 120 pp.

Cole, P.J., Wynnyk, W.P., and J.R. Gunson. 1977. Biological observations of wolves from the 1976-1977 wolf control program. Alberta Rec. Park and Wildl., Fish and Wildl. Div Rpt.

Commission on Life Science. 1997. Wolves, Bears, and Their Prey in Alaska: Biological and Social Challenges in Wildlife Management. Washington, DC: National Academy Press. 207 pp.

COSEWIC. 2003. COSEWIC assessment and update status report on the wolverine *Gulo gulo* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 41 pp.

Cowan, I. McT. 1947. The timber wolf in the Rocky Mountain National Parks of Canada. Can. J. Res. 25: 139-174.

Daubenmire, R. 1968. Ecology of fire in grasslands. Pp 209-266. *In* J.B. Cragg (ed): Advances in ecological research. Vol. 5, Academic Press, New York.

Dauphine, T.C. 1989. Updated status report on the wolverine (*Gulo gulo*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 25 pp.

Day, R.J. 1972. Stand structure, succession, and use of southern Alberta's rocky mountain forests. Ecology 53: 472-478.

Dawson, G.M. 1886. Preliminary report on the physical and geological features of that portion f the Rocky Mountains between latitudes 49 degrees and 51 degrees 30'. Pp 36B-37B *in* Geological & Natural History Survey of Canada. Annual report, Volume 1, 1885. Cited in Murphy (1985).

Delisle, G.P., and R.J. Hall. 1987. Forest fire history maps of Alberta – 1931 to 1983. Can. For. Serv., North. For. Cent. Edmonton, Alberta. 55 pp. + maps.

Dhir, N., Allen, L., and K. Vujnovic. 2003. Limber and Whitebark Pine Management in Alberta. Pp.10-11 *in* Parks Canada (ed). Whitebark and Limber Pine Workshop-Workshop Proceedings, February 18th and 19th, 2003. Calgary, AB.

Dix, R.L. 1960. The effects of burning on the mulch structure and species composition of grasslands in western North Dakota. Ecology 41: 49-56.

Doerksen, T. 1998. Chinook winds. http://www.ucalgary.ca/~doerksen/chinook.html. [Accessed 2003 March 31].

England, R.E., and A. DeVos. 1969. Influence of animals on pristine conditions on the Canadian grasslands. J. Range Manage. 22: 87-94.

Environment Canada. 2002. Floods. http://www.ec.gc.ca/water/en/manage/floodgen/e_floods.htm. [Accessed 2003 August 10].

Epp, H.E. 1988. Dual dispersion strategy among bison. Plains Anthropologist 33: 309-320.

Fahrig, L. 2003. When is a Landscape Ecology Perspective important? An essay. http://www.carleton.ca/lands-ecol/whatisle.html#Fig3B. [Accessed 2003 July 26].

Fidler, P. 1793. Diary of Peter Fidler for the period of 1792-1793. Glenbow-Alberta Institute. Calgary, AB.

Figliuzzi, P. 2002. South Saskatchewan River sub-basin contributions to international and interprovincial water sharing agreements. Prepared for the South Saskatchewan River Basin Water Management Plan Steering Committee. Alberta Environment Pub. No. 703, Edmonton, AB. 28 pp. + appendix.

Fischbuch, C., and L. Brodersen. 1995. State of the Castle Wilderness. Fourth Annual Report prepared for the Castle-Crown Wilderness Coalition. Special Publication No. 10 of the Castle-Crown Wilderness Coalition. Pincher Creek, AB. 13 pp.

Flathead Transboundary Network. 1999. State of the Crown of the Continent Ecosystem: Flathead/ Castle Transboundary Region (Draft). Miistakis Institute for the Rockies, Calgary, AB. 130 pp. + appendices.

Franzmann, A.W., Schwartz, C.C., and R.O. Peterson. 1980. Moose calf mortality in summer on the Kenai Peninsula, Alaska. J. Wildl. Manage. 44: 764-765.

Fredston, J.A. and D. Fesler. 1984: Snow sense – a guide to evaluating snow avalanche hazard. Department of Natural Resources, Division of Parks and Outdoor Recreation, Anchorage, AK

Fuller, T.K., and L.B. Keith. 1980. Wolf population dynamics and prey relationships in northeastern Alberta. J. Wildl. Manage. 44: 583-602.

Fuller, T.K., and L.B. Keith. 1981. Non-overlapping ranges of coyotes and wolves in northeastern Alberta. Journal of Mammalogy 62: 403-405.

Gauthier, D. A., Lafon, A., Toombs, T.P., Hoth, J., and E. Wiken. 2003. Grasslands: Toward a North American Conservation Strategy. Commission for Environmental Cooperation and Canadian Plains Research Center. Saskatoon, SK. 99 pp.

Gibbard, M.J., and D.H. Sheppard. 1992. Castle Wilderness environmental inventory. Prepared for the Castle-Crown Wilderness Coalition. Castle-Crown Wilderness Coalition, Spec. Pub. No. 1, Pincher Creek, AB. 168 pp.

Glenn, J. 2000. Once upon an Oldman: special interest politics and the Oldman River Dam. UNIpress. Geogretown, ON. 352 pp.

Golder Associates Ltd. 2003. Strategic overview of riparian and aquatic condition of the South Saskatchewan River Basin. Report submitted to Alberta Environment. Pub. No 706. Calgary, AB. 29 pp. + appendices.

Gunson, J.R. 1983. Status and management of wolves in Alberta. Pp. 25-29 *in* L.N. Carbyn (ed.). Wolves in Canada and Alaska : their status, biology, and management. Canadian Wildlife Service Report Series Number 45. Ottawa, ON.

Gunson, J.R., Jalkotzy, M., Carbyn, L.N., and L.D. Roy. 1993. Predation. Pp. 69-80 *in* J.B. Stelfox (ed.). Hoofed mammals of Alberta. Lone Pine Publishing, Edmonton, AB.

Hamer, D., and S. Herrero. 1983. Ecological studies of the grizzly bear in Banff National Park. Parks Canada Contract WR 4-80. University of Calgary, Calgary, AB. 303 pp.

Hamer, D. and S. Herrero. 1991. Elk, *Cervus elaphus*, calves as food for grizzly bears, *Ursus arctos*, in Banff National Park, AB. Can. Field-Nat. 105: 101-103.

Hamer, D., Herrero, S., and K. Brady. 1985. Studies of the grizzly bear in Waterton Lakes National Park: final report. Parks Canada, Calgary, AB. 185 pp.

Hamer, D., Herrero, S., and K. Brady. 1991. Food and habitat used by grizzly bear, *Ursus arctos*, along the Continental Divide in Waterton Lakes National Park, Alberta. Can. Field-Nat. 105: 325-329.

Hanson, J.R. 1984. Bison ecology in the northern plains and a reconstruction of bison patterns for the North Dakota region. Plains Anthropologist 29: 83-113.

Harris, R.B. 1981. The status of wolves in the Livingstone-Porcupine area of southern Alberta- a preliminary report. Unpublished document. University of Montana, Missoula, MT. 33 pp.

Harris, R.B. 1982. Progress report: Effects of elk migration and cattle distribution on wolf movements in southern Alberta. Unpublished document. University of Montana, Missoula, MT. 11 pp.

Hawkes, B.C. 1979. Fire history and fuel appraisal study of Kananaskis Provincial Park, Alberta. Dep. Forest Sci., University of Alberta, Edmonton, AB. 173 pp.

Heitzmann, R.J. 2001. Identifying human ignited fires in the central Canadian Rockies over the last millennium. Pp.169-178 *in* Pilon, J.L., Kirby, M.W., and C. Thériault. A collection of papers presented at the 33rd Annual Meeting of The Canadian Archeological Association. The Ontario Archaeological Society Inc. and The Canadian Archaeological Association, Ottawa, ON.

Higgins, K.F. 1984. Lightning fires in North Dakota grasslands and pine-savanna Lands of South Dakota and Montana. J. Range Manage. 37: 100-103.

Higgins, K.F. 1986. Interpretation and compendium of historical fire accounts in the Northern Great Plains. U.S. Fish & Wildlife Service Res. Pub. 161. 39 pp.

Higgins, K. F., Kruse, A.D., and J. L. Piehl. 1989. Effects of fire in the Northern Great Plains. U.S. Fish and Wildlife Service and Cooperative Extension Service, South Dakota State University, Brookings, South Dakota. Extension Circular 761. Jamestown, ND: Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/2000/fire/fire.htm. (Version 16MAY2000). [Accessed 2003 August 12].

Hnatiuk, R.J. 1969. The *Pinus contorta* vegetation of Banff and Jasper National Parks. M.Sc. thesis. Dep. Botany, University of Alberta, Edmonton, AB. 319 pp.

Holcroft, A.C., and S. Herrero. 1991. Black bear, *Ursus americanus*, food habits in southwestern Alberta. Can. Field-Nat. 105: 335-345.

Hornocker, M.G. and H.S. Hash. 1981. Ecology of the wolverine in northwestern Montana. Can. J. Zool. 59: 1286-1301.

Howard, J.L. 2002, July. *Pinus albicaulis*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/. [Accessed 2004 January 27].

Huff, M.H., and J.K. Smith. 2000. Fire effects on animal communities. Pp. 35-42 *In*: J. Kapler Smith, ed. Wildland fire in ecosystems: effects of fire on fauna. Gen. Tech. Rep.

RMRS-GTR-42-vol. 1. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Ogden, UT. 83 pp.

Huculak, C. and D. Little. 1999. Kananaskis virtually – vegetation; temporal variables. http://www.ucalgary.ca/UofC/faculties/SS/GEOG/Virtual/kanframeset.html. [Accessed 2003 March 31].

Johnson, K.A. 2001 March. *Pinus flexilis*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (2002, April). Fire Effects Information System, [Online]. Available: http://www.fs.fed.us/database/feis/. [Accessed 2003 September 6].

Johnston, A., Dormaar, J.E., and S. Smoliak. 1971. Long-term grazing effects on fescue grassland soils. J. Range Manage. 24: 185-188.

Johnston, A., and S. Smoliak. 1968. Reclaiming brushland in southwestern Alberta. J. Range Manage. 21: 404-406.

Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in fescue grassland of southwestern Alberta. Can. J. Plant Sci. 41: 615-622.

Johnston, A. 1962. Effects of grazing intensity and cover on the water-intake rate of fescue grassland. J. Range Manage. 15: 79-87.

Kansas, J.L., and R.N. Riddell. 1995. Grizzly bear habitat model for the four contiguous mountain national parks: Second Iteration. Canadian Parks Service, Calgary, AB. 109 pp.

Kay, C.E., and C.A. White. 2001. Reintroduction of bison into the Rocky Mountain parks of Canada: historical and archeological evidence. Pp.143-151 *in* Harmon, D. (ed.). Crossing Boundaries in Park Management: Proceedings of the 11th Conference on Research and Resource Management in Parks and on Public Lands. The George Wright Society, Hancock, Michigan.

Kay, C.E., White, C.A., Pengelly, I.R., and B. Patton. 1999. Long-term ecosystem states and processes in Banff National Park and the Central Canadian Rockies. Parks Canada, National Parks Branch, Occasional Report 9, Ottawa, ON. Various pagings.

Kendall, K. C. 1998. Limber pine. P. 486 *in* Mac, M.J., Opler, P.A., Haecker, C.E.P., and P.D. Doran, (eds). Status and trends of the nations biological resources. 2 Vols. U.S.Dept. of the Interior. U.S. Geological Survey, Reston, VA. Also available on line: http://biology.usgs.gov/s+t/SNT/index.htm.

Kendall, K.C., Ayers, D., and D. Schirokauer. 1996. Limber Pine Status from Alberta to Wyoming. Nutcracker Notes 7: 23-24.

Kolenosky, G.B., and S.M. Strathearn. 1987. Black bear. Pp. 443-454 *in* M. Novak, J.A. Baker, M.E. Obbard, and B. Malloch (eds). Wild furbearer management and conservation in North America. Ontario Ministry of Natural Resources, Toronto, ON.

Krajick, K. 1998. Animals thrive in an avalanche's wake. Science 279: 1853.

Langemann, E.G. 2000. Stable carbon isotopic analysis of archeological bison bone: using zooarcheology to address questions of the past ecology of bison. Research Links 8: 4, 12

Larson, F. 1940. The role of bison in maintaining the shortgrass prairie. Ecology 21: 113-121.

Leavitt, P.R., and G. Chen. 2001. Sustainable agriculture in Western Canada: Planning for droughts using the Past. Unpublished report, University of Regina, Regina, SK. Available at http://www.uregina.ca/biology/faculty/leavitt/drought/update00/FinalReport.htm. [Accessed 2003 September 17].

Lee, P. 1999. Ecosystem Management and this project. *In*: Alberta Research Council. Fire and Harvest Residual (FAHR) Project: The impact of wildfire and harvest residuals on forest structure and biodiversity in aspen-dominated boreal forests of Alberta. Alberta Environment Pub. No. T/495. Edmonton, AB. 11 pp. Available: http://www.abmp.arc.ab.ca/AnnualReport2003.pdf . [Accessed 2004 March 11].

Lemmen, D., Vance, R., Wolfe, S., and Last, W. 1997. Impacts of future climate change on the southern Canadian prairies: a paleoenvironmental perspective. Geoscience Canada 24: 121-133.

Levin, H.L. 1988. The earth trough time. 3rd ed. Saunders College Publishing. New York. 593 pp.+ appendices.

Logan, J.A., and J.A. Powell. 2001. Ghost forests, global warming, and the mountain pine beetle (Coleoptera: Scolytidae). American Entomologist 47(3): 160-172.

Lyon, L.J., Brown, J.K., Huff, M.H., and J. Kapler Smith. 2000a. Introduction. Pp. 1-7 *in* J. Kapler Smith, ed. Wildland fire in ecosystems: effects of fire on fauna. Gen. Tech. Rep. RMRS-GTR-42-vol. 1. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Ogden, UT.

Lyon, L.J., Hooper, R.G., Telfer, E.S., and D.S. Schreiner. 2000b. Fire effects on wildlife food. Pp. 51-58 *In*: J. Kapler Smith, ed. Wildland fire in ecosystems: effects of fire on fauna. Gen. Tech. Rep. RMRS-GTR-42-vol. 1. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Ogden, UT.

MacCallum, B. 2001. Status of the harlequin duck (*Histrionicus histrionicus*) in Alberta. Alberta Sustainable Resource Development, Fisheries and Wildlife Management Division, and Alberta Conservation Association, Wildlife Status Report No. 36, Edmonton, AB. 38 pp.

Malainey, M.E., and B.L. Sherriff. 1996. Adjusting our perceptions: historical and archeological evidence of winter on the plains in western Canada. Plains Anthropologist 41: 333-357.

Malanson, G.P. and D.R. Butler.1984. Transverse pattern of vegetation on avalanche paths in the northern Rocky Mountains, Montana. Great Basin Naturalist 44: 453–58.

Malanson, G.P. and D.R. Butler. 1986: Floristic patterns on avalanche paths in the northern Rocky Mountains, USA. Physical Geography 7: 231–38.

Mathews, N.E., and W.F. Porter. 1988. Black bear predation of white-tailed deer neonates in the central Adirondacks. Can. J. Zool. 66: 1241-1242.

McDougall, J. 1971. Pathfinding on plain and prairie: stirring scenes of life in the Canadian North-West. Coles Publishing Company, Toronto, ON. 277 pp.

McLean, A. 1969. Fire resistance of forest species as influence by root systems. J. Range Manage. 22: 120-122.

McLean, A., and S. Wikeem. 1985. Rough fescue response to season and intensity of defoliation. J. Range Manage. 38: 100-103.
Mech, L.D. 1981. The wolf: the ecology, and behavior of an endangered species. University of Minnesota Press, Minneapolis, MN. 384 pp.

Miller, M. 2000. Fire Autecology. Pp 9-34 *in* Brown, J. K., and J. Kapler Smith (eds). Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Miistakis Institute for the Rockies. 1998. Threats and opportunities: the elk and grizzly of the Castle Region, south-western Alberta. Miistakis Institute, Calgary, AB. 33 pp.

Moodie, D.W., and A.J. Ray. 1976. Buffalo migrations on the Canadian plains. Plains Anthropologist 21: 45-52.

Morgan, R.G. 1980. Bison movement patterns on the Canadian plains: An ecological analysis. Plains Anthropologist 25: 143-160.

Moss, E.H., and J.A. Campbell. 1947. The fescue grassland of Alberta. Can. J. Res. 25: 209-227.

Mowat, G. 2001. Measuring wolverine distribution and abundance in Alberta. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 32, Edmonton, AB. 22 pp.

Mowat, G., Kyle, C., and D. Paetkau. 2003. Testing methods for detecting wolverine. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 71, Edmonton, AB. 10 pp.

Mowat, G., and C. Strobeck. 2000. Estimating population size of grizzly bears using hair capture, DNA profiling, and mark-recapture analysis. J. Wildl. Manage 64: 183-193.

Muhs, D.R., Wolfe, S.A., 1999. Sand dunes of the Northern GreatPlains of Canada and the United States. Geological Survey of Canada Bulletin 534: 183–197.

Murphy, P.J. 1985. History of Forest and Prairie Fire Control Policy in Alberta. Alberta Energy and Natural Resources, Forest Service. Edmonton, AB. 408 pp.

Murphy, P.J., Udell, R., and R.E. Stevenson. 2002. The Hinton Forest 1955-2000: a case study in adaptive forest management - the Weldwood-Hinton story. Chapter 1: Introduction and background. Foothills model forest history series, vol. 2. Hinton, AB. 66 pp. Available: http://www.fmf.ab.ca/AFM/AFM_Ch1.pdf. [Accessed 2004 March 12].

Mustapha, A.M. and S. Figliuzzi. 1985. History of floods in the Oldman River Basin. Water Resources, Alberta Environment. Unpublished Report. 161 pp.

Mutch, R.W. 1970. Wildland fires and ecosystems: a hypothesis. Ecology 51: 1046-1051.

Naeth, M.A., and D.S. Chanasyk. 1995. Grazing effects on soil water in Alberta foothills fescue grasslands. J. Range Manage. 48: 528-534.

Naeth, M.A., Bailey, A.W., Pluth, D.J., Chanasyk, D.S., and R.T. Hardin. 1991. Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. J. Range Manage. 44: 7-12.

Natural Resources Canada. 2002. The winds of change: Climate change in Prairie Provinces. http://www.adaptation.nrcan.gc.ca/posters/reg_en.asp?Region=pr. [Accessed 2003 March 31].

Nelson, J.G., and R.E. England. 1971. Some comments of the causes and effects of fire in the northern grasslands area of Canada and the nearby United States, ca. 1750-1900.

Nielsen, P.L. 1975. The past and present status of the plains and boreal forest grizzly bear in Alberta. Canadian Wildlife Service, Edmonton, AB. 61 pp.

Nowak, R.M. 1978. Evolution and taxonomy of coyotes and related *Canis*. Pp. 3-16 *in* M. Bekoff (ed). Coyotes : biology, behavior and management. Academic Press, New York, NY.

Oldman River Basin Water Quality Initiative. 2002. Oldman River Basin Water Quality and Land Use Interactive Map and Data CD, Version 1.0. [CD-ROM]. Lethbridge, AB.

Oldman River Dam Environmental Advisory Committee. 2001. Final Recommendations. Pub. No I/906. Alberta. 33 pp.

Ostlie, W.R., Schneider, R.E., Aldrich, J.M., Faust, T.M., McKim, R.L.B., and S. J. Chaplin. 1997. The status of biodiversity in the Great Plains. The Nature Conservancy, Arlington, VA. 326 pp. Also available on-line: http://www.greatplains.org/resource/biodiver/biostat/biostat.htm.

Parks Canada (ed.). 2003. Whitebark and Limber Pine Workshop-Workshop Proceedings, February 18th and 19th, 2003, Calgary, AB. 39 pp.

Pattie, D.L, and C. Fisher. 1999. Mammals of Alberta. Lone Pine Publisher, Edmonton, AB. 240 pp.

Pelton, M.R. 1982. Black bear. Pp. 504-514 *in* J.A. Chapman and G.A. Feldhamer (eds). Wild mammals of North America : biology, management, and economics. Johns Hopkins University Press, Baltimore, MD.

Petersen, S. 1997. Status of the Wolverine (*Gulo gulo*) in Alberta. Alberta Environmental Protection, Wildlife Management Division, Wildlife Status Report No. 2, Edmonton, AB. 17 pp.

Post, J.R., and F.D. Johnston. 2002. Status of the Bull Trout (Salvelinus confluentus) in Alberta. Alberta Sustainable Resource Development, Fish and Wildlife Division, and Alberta Conservation Association, Wildlife Status Report No. 39, Edmonton, AB. 40 pp.

Pritchard, H. D., and C. T. Robbins. 1990. Digestive and metabolic efficiencies of grizzly bears and black bears. Can. J. Zool. 68: 1645-1651.

Poole, K.G., and G. Mowat. 2001. Alberta furbearer harvest data analysis. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 31. Edmonton, AB. 51 pp.

Quinlan, R.W., B.A. Downey, B.N. Taylor, P.F. Jones, and T.B. Clayton (eds.). 2003. A multi-species conservation strategy for species at risk in the Milk River basin: year 1 progress report. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 72, Edmonton, AB. 229 pp.

Ream, R.R., and R. Harris. 1986. Wolf movements in southern Alberta. Nat. Geog. Soc. Res. Rep. 21: 405-409.

Roe, F.G. 1970. The North American buffalo: a critical study of the species in its wild state. 2nd ed. University of Toronto Press, Toronto, ON. 991 pp.

Roed, M.A. 2001. Geologic History of Okanagan Valley and Origin of Lake Okanagan, British Columbia. Geoscapes website. Available: http://www.geoscapes.ca/pov/okhistory.html. [Accessed 2004 March 9].

Rood, S.B., Kalischuk, A.R., and J.M. Mahoney. 1998. Initial cottonwood seedling recruitment following the flood of the century of the Oldman river, Alberta, Canada. Wetlands 18: 557-570.

Rood, S.B., and J. M. Mahoney (eds). 1991. The biology and management of Southern Alberta's cottonwoods. University of Lethbridge, Lethbridge, AB. 124 pp.

Rood, S.B., and J. M. Mahoney. 1995. River Damming and Riparian Cottonwoods Along the Marias River, Montana. Rivers: 5: 195-207.

Ross, P.I., and M.G. Jalkotzy. 1992. Characteristics of a hunted population of cougars in southwestern Alberta. J. Wildl. Manage. 56: 417-426.

Rowe, J.S. 1969. Lightning fires in Saskatchewan grassland. Can. Field Nat. 83: 317-324.

Russell, R.H., Nolan, J.W., Woody, N.G., and G.H. Anderson. 1979. A study of the grizzly bear in Jasper National Park 1975 to 1978. Canadian Wildlife Service, Edmonton, AB. 102 pp. + appendices.

Ryder, J.M. 1998. Geomorphological processes in alpine areas of Canada: the effects of climate change and their impacts on human activities. Geological Survey of Canada, Bulletin 524: 44 pp.

Sadler, B. 1974. An analysis of public views on the Oldman River Basin. PP. 13-30 *in* Alberta Environment Conservation Authority. Land use and resource development in the eastern slopes. Interim report No. 2 – Oldman River Basin. Environment Conservation Authority, Edmonton, AB.

Sawyer, M., Mayhood, D., Paquet, P., Wallis, C., Thomas, R., and W. Haskins. 1997. Southern east slopes cumulative effects assessment. Prepared by Hayduke and Associates Ltd., Calgary, AB, with funding from Morrison Petroleums Ltd., Calgary, AB. 207 pp. + appendices. Also available on-line at: <http://www.hayduke.ca/science/sescea.html >.

Seton, E.T. 1929. Lives of game animals. Vol. III, part II. Doubleday, Doran & Co., N.Y. 780 pp.

Soper, J.D. 1964. The mammals of Alberta. Hamley Press : Dept. of Industry and Development, Edmonton, AB. 402 pp.

Soper, J.D. 1973. The mammals of Waterton Lakes National Park Alberta. Canadian Wildlife Service Report Series No. 23. Environment Canada, Ottawa, ON. 57 pp.

Smit, B., Burton, I., Klein, R.J.T., and J. Wandel. 2000. An anatomy of adaptation to climate change and variability. Climatic Change, 45: 223-151.

Smith, H.C. 1993. Alberta mammals: an atlas and guide. The Provincial Museum of Alberta. Edmonton, AB. 238 pp.

Smoliak, S., Ditterline, R.L., Scheetz, J.D., Holzworth, L.K., Sims, J.R., Wiesner, L.E., Baldridge, D.E., and G.L. Tibke. 2003. Information and publications - Grass Species. *In*: Animal and Range Sciences, Montana State University Extension Service. Available: http://animalrangeextension.montana.edu/Articles/Forage/Species/Grasses/GrassSpeciesList.htm. [Accessed 2003 September 18].

Spalding, D.J., and J. Lesowski. 1971. Winter food of the cougar in south-central British Columbia. J. Wildl. Manage. 35: 378-381.

Spatial Data Warehouse. 1982. 1:20 000 digital base maps - feature: hydrography. Spatial Data Warehouse. AltaLIS Ltd. Calgary, AB.

Spatial Data Warehouse. 1995. Native Prairie Vegetation Inventory. Data Warehouse. AltaLIS Ltd. Calgary, AB.

Stelfox, J.G. 1969. Wolves in Alberta: a history 1800-1969. Alberta Lands, Forests, Parks, Wildlife 12: 18-27.

Strahler, A.N., and A.H. Strahler. 1987. Modern physical geography. 3rd ed. John Wiley & Sons, New York. 544 pp.

Stringer, P.W, and G.H. La Roi. 1970. The Douglas-fir forests of Banff and Jasper National Parks, Canada. Can. J. Bot. 48: 1703-1726.

Tande, G.F. 1979. Fire history and vegetation pattern of coniferous forests in Jasper National Park, Alberta. Can. J. Bot. 57: 1912-1931.

Thomas, H.S. 1991. Buffalo, early range users. Rangelands 13: 285-287.

Thompson, D. 1962. Narrative, 1784-1812 *in* R. Glover (ed.). Champlain Society, Toronto, ON. 410 pp.

Todd, A.W., Keith, L.B., and C.A. Fisher. 1981. Coyote demography during a snowshoe hare decline in Alberta. J. Wildl. Manage 45:629-640.

Tomback, D.F. 2003.Whitebark pine: status, trends, strategies in the U.S.A. Pp.5-7 *in* Parks Canada (ed). Whitebark and Limber Pine Workshop-Workshop Proceedings, February 18th and 19th, 2003. Calgary, AB.

Toweill, D.E. 1977. Food habits of cougars in Oregon. J. Wildl. Manage. 41:576-578.

Timoney, K. 1998. Environmentally Significant Areas Inventory of the Rocky Mountain Natural Region of Alberta. Unpublished report for Corporate Management Service, Alberta Environmental Protection, Edmonton, AB. 67 pp. + appendices.

Trimble, D.E. 1980. The geologic story of the Great Plains. Geological Survey Bulletin No.1493. United States Government Printing Office, Washington. 55 pp. (out of print). Available: http://www.lib.ndsu.nodak.edu/govdocs/text/greatplains/text.html. [Accessed 2003 July 28].

Uchytil, R. J. 1992. *Pinus contorta* var. *latifolia*. *In*:U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (2003, August). Fire Effects Information System, [Online]. Available: http://www.fs.fed.us/database/feis/. [Accessed 2003 September 2].

U.S. Fish and Wildlife Service. 1987. Northern Rocky Mountain Wolf Recovery Plan. U.S. Fish and Wildlife Service, Denver, Colorado, 119 pp. Also available on-line at: http://midwest.fws.gov/wolf/west/nr-recplan.pdf.

USDA, NRCS. 2002. The PLANTS Database, Version 3.5 (http://plants.usda.gov.). National Plant Data Center, Baton Rouge, LA 70874-4490 USA. [Accessed 2003 September 18].

Van Vuren, D. 1979. Ecology and behavior of bison in the Henry Mountains, Utah. M.S. Thesis, Oregon State University, Corvallis, Oregon. 39 leaves.

Van Vuren, D. 1983. Group dynamics and summer home range of bison in southern Utah. J. Mammal. 64: 329-332.

Van Vuren, D.H. 2001. Spatial relations of American bison *Bison bison* and domestic cattle in a montane environment. Animal Biodiversity and Conservation 24: 117-124.

Verspoor, E. 1983. Black bear, *Ursus americanus*, predation on mule deer fawn, *Odoceileus hemionus*. Can. Field-Nat. 97: 114.

Vogl, R.J. 1974. Effects of fires on grasslands. Pp 139-194. *In* Kozolowski, T.T., and C.E. Ahlgren (eds), Fire and ecosystems. Academic Press, New York. 542 pp.

Voigt, D.R., and W.E. Berg. 1987. Coyote. Pp. 344-357 *in* M. Novak, J.A. Baker, M.E. Obbard, and B. Malloch (eds). Wild furbearer management and conservation in North America. Ontario Ministry of Natural Resources, Toronto, ON.

Vujnovic, K. and J. Gould. 2002. Alberta Natural Heritage Information Centre Tracking and Watch Lists - Vascular Plants, Mosses, Liverworts and Hornworts. Alberta Community Development, Parks and Protected Areas Division, Edmonton, Alberta. 36 pp + appendix.

Waller, J.S. and R.D. Mace. 1997. Grizzly bear habitat selection in the Swan Mountains, Montana. J. Wildl. Manage 61: 1032-1039.

Wallis, C., Bradley, C. Fairbarns, M., Packer, J., and C. Wershler. 1986. Pilot rare plant monitoring program in the Oldman Regional Plan area of southwestern Alberta. Prepared for Alberta Forestry, Lands and Wildlife, Pub. No. T/148. Edmonton, AB. 203 pp.

Walter, D.W., Adams, B.W., and J. F. Dormaar. 1996. Seasonal changes of herbage biomass on the fescue prairie. J. Range Manage. 49: 100-104.

Webster, K.L., and E. A. Johnson. 2000. The importance of regional dynamics in local populations of limber pine (*Pinus flexilis*). Ecoscience 7(2): 175-182.

White, C.A., Langemann, E.G., Gates, C.C., Kay, C.E., Shury, T., and T.E. Hurd. 2001. Plains bison restoration in the Canadian Rocky Mountains? Ecological and management considerations. Pp. 152-160 *in* Harmon, D. (ed). Crossing Boundaries in Park Management: Proceedings of the 11th Conference on Research and Resource Management in Parks and on Public Lands. The George Wright Society, Hancock, MI.

Willoughby, M.G., Alexander, M. J., and B. Adams. 2003. Range plant community types and carrying capacity for the montane subregion: fifth approximation. Environment, Lands and Forest Services, Edmonton, AB. 223 pp.

Wilton, M.L., Carlson, D.M., and C.I. McCall. 1984. Occurrence of neonatal cervids in the spring diet of black bear in south central Ontario. Alces 20: 95-105.

World Resource Institute. 2000. World Resources 2000-2001: People and ecosystems: The fraying web of life. United Nations Development Programme, United Nations Environment Programme, World Bank, World Resources Institute. Available: http://forests.wri.org/pubs_pdf.cfm?PubID=3027. [Accessed 2003 August 8].

Wright, H.A., and A.W. Bailey. 1982. Fire ecology – United States and Southern Canada. Wiley-Interscience, New York, NY. 501 pp.

Wuerthner, G. 1998. Are cows just domesticated bison? Behavioural and habitat use differences between cattle and bison. Pp. 374-383 *in* Irby, L. and J. Knight (eds).

International symposium on bison ecology and management in North America. Montana State University, Bozeman, MT.

Appendix 1. Definition of categories for "The General Status of Alberta Wild Species 2000". Modified from Alberta Sustainable Resource Development (2001).

Category	Definition
At Risk	Any species known to be "At Risk" after formal detailed status assessment and designation as "Endangered" or "Threatened" in Alberta.
May Be At Risk	Any species that "May Be At Risk" of extinction or extirpation, and is therefore a candidate for detailed risk assessment.
Sensitive	Any species that is not at risk of extinction or extirpation but may require special attention or protection to prevent it from becoming at risk.
Secure	A species that is not "At Risk" "May Be At Risk" or "Sensitive".
Undetermined	Any species for which insufficient information, knowledge or data is available to reliably evaluate its general status.
Not Assessed	Any species that has not been examined for the report.
Exotic/Alien	Any species that has been introduced as a result of human activities.
Extirpated/Extinct	Any species no longer thought to be present in Alberta ("Extirpated") or no longer believed to be present anywhere in the "World".
Accidental/Vagrant	Any species occurring infrequently and unpredictably in Alberta, i.e., outside its usual range. (These species may be in Alberta due to unusual weather occurences, an accident during migration, or unusual breeding behaviour by a small number of individuals. If a species appears in Alberta with increasing predictability and more frequently, it may eventually be given a different rank. Changes in "Accidental/Vagrant" species may be a good indicator of general ecosystem or climatic changes.)

Appendix 2. Alberta Natural Heritage Information Centre's ranking system. Modified from Vujnovic and Gould (2002).

Elements (of biodiversity) are evaluated and ranked on their status (globally and state/provincially) using a system developed by The Nature Conservancy that is in use throughout North America. Ranking is usually based primarily on the number of occurrences, since that is frequently the only information available. Information, such as population size and trend, life history and reproductive strategies, range and current threats is used when available.

Provincially the ranks in Alberta are defined as:

S1: < 5 occurrences or only a few remaining individuals.
S2: 6-20 occurrences or with many individuals in fewer occurrences.
S3: 21-100 occurrences may be rare and local throughout its range, or in a restricted range (may be abundant in some locations or may be vulnerable to extirpation because of some factor of its biology).
S4: apparently secure under present conditions, typically >100 occurrences but may be fewer with many large populations; may be rare in parts of its range, especially peripherally.
S5: demonstrably secure under present conditions, > 100 occurrences, may be rare in parts of its range, especially peripherally.
SU: status uncertain often because of low search effort or cryptic nature of the element; possibly in peril, unrankable, more information needed.
SH: historically known, may be relocated in the future.

Other codes are:
E: exotic species established, may be native to nearby regions
HYB: hybrid taxon that is recurrent in the landscape
P: potentially exists; may have occurred historically (but having not been persuasively documented)
Q: taxonomic questions or problems
R: reported but lacking sufficient documentation to accept or reject
RD: report dubious
RF: reported falsely
T_: rank for a subspecific taxon
X: believed to be extirpated
S?: not yet ranked
_?: rank questionable